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# Systematisch-vergleichende Morphologie und Anatomie der Vegetationsorgane der japanischen Bambus-Arten.

**von**

**Yoshio TAKENOUCHI.**

Mit 3 Tafeln und 29 Textfiguren.

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## I. Allgemeiner Teil.

Die systematische Diagnosierung der Bambusarten auf Grund des Baues ihrer Blütenorgane ist nicht immer durchführbar, manchmal sogar unmöglich, da die meisten nur selten blühen, und zwar mit Intervallen von einigen Jahrzehnten (BRANDIS, '74; KAWAMURA, '11, '27; LÖW, '05; MACMILLAN, '08; SUESSENGUTH, '25). Die Vegetationsorgane hingegen sind stets zugänglich; daher erscheint es sehr wünschenswert, die Bambusgewächse auf Grund der Morphologie und Anatomie dieser Organe systematisch einzuteilen.

In Japan gibt es seit altersher viele Skizzen und Einzelbeschreibungen verschiedener Bambusarten, die jedoch keine zusammenfassende Diagnosierung der Vegetationsorgane bieten. Erst SATOW ('99) hat darauf hingewiesen, dass z. B. das Auftreten oder Fehlen der Rinnen an den Internodien des Stengels, die Längenverhältnisse der Blattscheide, die durchschnittliche Lebensdauer der Blattscheide, das Auftreten oder Fehlen von hervortretenden Knoten usw. als ausgezeichnete Merkmale zu betrachten sind.

Es gibt nun bei den Bambusarten noch viele andere Merkmale der Vegetationsorgane, zumal des Rhizoms, des Stengels, des Blattes, sowie der Knospe, welche die Gattungen charakterisieren und kaum von äusseren Verhältnissen beeinflusst zu sein scheinen. Schon früher hat MAKINO ('25) bei der Klassifizierung der japanischen Bambusgewächse nicht nur den Blütenbau, sondern auch die morphologischen Eigenschaften der vegetativen Organe verwendet.

Die Anwendung der Pflanzenanatomie im Dienste der Systematik ist seit RADLKOEFER ('83) von einer Anzahl von Autoren versucht und geübt worden. So z. B. von NIEDENZU ('89) für Arbutoiden, LOHAUSS ('05) für Festucaceen, SOLEREDER ('99, '03, '28, '29) für Dikotyledonen und Monokotyledonen, KANEHIRA ('21) für die in Formosa vorkommenden Holzarten, GLEICHBERG ('22) für *Vaccinium Oxycoccus*, OGURA ('27a, '27b) für Pteridophyten, HAYATA ('27) für Filicales. Bei den Monokotylen hat ZAWADA ('90) die anatomische Blattstruktur für die Systematik der Palmen verwendet. JESWIET ('16) hat die Zuckerrohr-Sorten nach besonderen, topographischen Merkmalen der Vorblatthaare eingeteilt. Von SHIBATA u. MAKINO ('00) liegt eine wichtige Arbeit vor, in welcher die Gattung *Sasa* auf Grund der Anatomie der Wurzel ganz von der Gattung *Bambusa* abgesondert wird. Die systematische Anatomie der Blattepidermis der Gattung *Sasa* hat in der neuesten Zeit HAYATA ('29) ausgearbeitet.

Bei den Bambusgeleichen, mit welchen ich seit einer Reihe von Jahren beschäftigt bin, sind die morphologischen, bzw. vergleichend-anatomischen Merkmale insofern von besonderer Bedeutung, als sie sich als Gattungsmerkmale systematisieren lassen. Als hauptsächlichste Merkmale mögen hier folgende kurz aufgezählt werden:

1) Morphologische und anatomische Merkmale der Halme; 2) morphologische Eigenschaften und Verzweigungsmodi der unterirdischen Organe; 3) Form der Knospen; 4) Eigentümlichkeiten der Vorblätter; 5) Zahl der Knospen in einem Vorblatt; u. a. m.

Morphologisch und vergleichend-anatomisch lässt sich der Bambushalm in drei Regionen einteilen, nämlich:

1. Der echte Halm, 2. der Übergangshalm oder die Stengelbasis, und 3. der gestauchte, rhizomähnliche Teil oder Stiel.

In bezug auf die Verzweigung des Rhizoms lassen sich folgende vier Typen unterscheiden :

1. Einfache Rasenbildung, 2. Rasenbildung aus Ausläufern, 3. seitliche Rasenbildung aus Rhizomen und 4. zerstreute Verzweigung.

Die Form der an jedem Knoten des Stengels hervortretenden Knospen ist je nach ihrer Lage am Stengel sowie nach der Gattung verschieden. Verfolgt man ferner die aufeinanderfolgenden Knospen von der Basis des Stengels nach oben, so findet man an den Vorblättern mehr oder weniger bedeutende Veränderungen des Spaltungs- oder Schliessungsgrades, eine Erscheinung, die ich als „Knospenfolge“ bezeichnen möchte. Bemerkenswert ist, dass diese Knospenfolge innerhalb einer und derselben Gattung nahezu konstant ist. Die Zahl der Knospen innerhalb eines Vorblattes ist nach der Spezies und nach der Lage am Stengel verschieden (siehe S. 37). Auch die anatomischen Merkmale der Vorblätter, in gewisser Hinsicht auch ihre Behaarung, sind in systematischer Hinsicht von grosser Bedeutung. Die morphologischen und anatomischen Verschiedenheiten all dieser Merkmale werden auf S. 40 zusammengestellt.

Die vorliegenden Untersuchungen wurden anfänglich in der Forst- und Landwirtschaftlichen Hochschule zu Taihoku in Formosa, später im Botanischen Institut der Kaiserlichen Universität in Kyoto ausgeführt. An dieser Stelle spreche ich meinem hochverehrten Lehrer Herrn Prof. Dr. K. KORIBA meinen wärmsten Dank für seine vielfache Belehrung und Anregung aus. Auch möchte ich Herrn Prof. Dr. K. OSHIMA für seine freundlichen Ratschläge und gütige Unterstützung bei der Beschaffung des Materials bestens danken.

## II. DAS RHIZOM.

### A. MORPHOLOGISCHE EIGENSCHAFTEN DES RHIZOMS.

**Verzweigungsmodi der unterirdischen Sprosse.** Das Rhizom der Bambuseen ist gewöhnlich im Gegensatz zum Stengel in kürzere Teilstücke von der Länge einiger Zentimeter gegliedert. Im Querschnitt zeigt es einen zentralen Hohlraum, welcher im Vergleich zu dem der

Stengel stark reduziert ist und besonders im oberirdischen Teil gänzlich verschwindet, wo er von einem stark entwickelten Grundparenchym ausgefüllt wird.

Unter den Verzweigungsmodi der unterirdischen Sprosse lassen sich folgende vier Typen unterscheiden.

1. Einfache Rasenbildung (Fig. 1, 1).

Bei *Dendrocalamus* und *Bambusa* entwickelt sich die Knospe an der Stengelbasis zum aufgerichteten Halm, und die Basalknospe des letzteren, ebenso wie alle weiteren Basalknospen verhalten sich in gleicher Weise, so dass als Folge dieses Verzweigungsmodus ein einfacher Rasen zu Stande kommt.

2. Rasenbildung am Ende der Ausläufer (Fig. 1, 2).

Bei *Arundinaria nitakayamensis* sieht man einen ähnlichen Verzweigungsmodus wie bei *Bambusa*, aber die Knospen an der Stengelbasis wachsen zu seitlichen Ausläufern aus, und jeder von diesen bildet, kurz bevor er in den aufgerichteten Halm übergeht, ebenfalls einen selbständigen Rasen. Die Ausläufer besitzen verhältnismässig kurzgestreckte, dünne, keine Knospen aufweisende Internodien.

3. Seitliche Rasenbildung aus dem Rhizom (Fig. 1, 3).

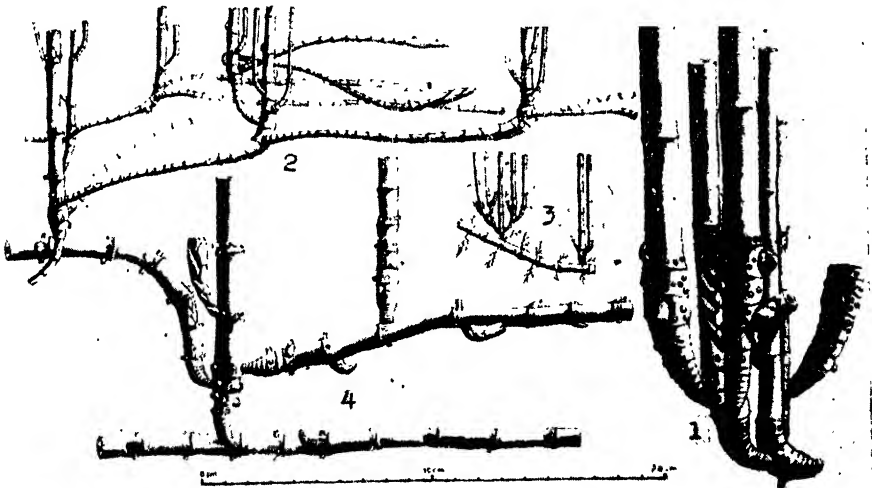


Fig. 1.

Verzweigungsmodi von unterirdischen Stengeln. 1 Einfache Rasenbildung von *Bambusa*, 2 Rasenbildung aus Ausläufern von *Arundinaria nitakayamensis*, 3 Seitliche Rasenbildung aus Rhizomen von *Shibataea*, 4 Zerstreute Verzweigung von *Phyllostachys*.

Bei *Pleioblastus*, *Sasa*, *Pseudosasa* u. a. findet man zwei Arten von unterirdischen Zweigen. Die an der Stengelbasis sitzenden Knospen wachsen zu langen, dünnen, mehrere Knospen entwickelnden horizontalen Rhizomen aus, welche schliesslich in Stengel übergehen. Die Knospen, die an jedem Knoten dieser Rhizome gebildet werden, entwickeln sich ebenfalls zu rasenbildenden Halmen.

4. Zerstreute Verzweigung (Fig. 1, 4).

Bei *Phyllostachys* findet man zerstreute Verzweigung. Das horizontale

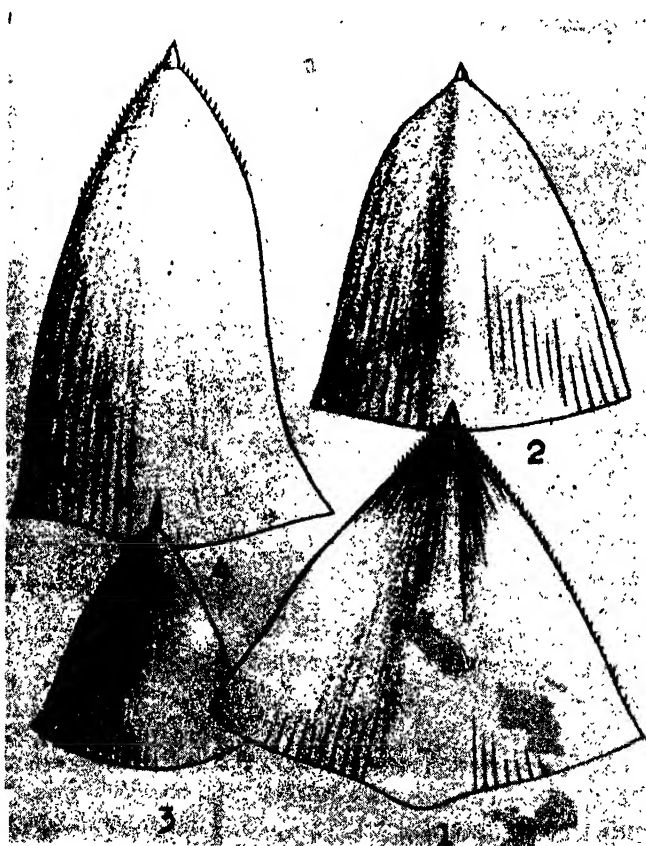


Fig. 2.

Scheidenblätter des Rhizoms mit verkümmelter Blattspreite :

1. *Phyllostachys reticulata*, var. *Marliacea*.
2. *Pseudosasa Kurilensis*, var. *nebulosa*.
3. *Pleioblastus variegata*, var. *viridis*, f. *major*.
4. *Semiarundinaria viridis*.       $\times 1$ .

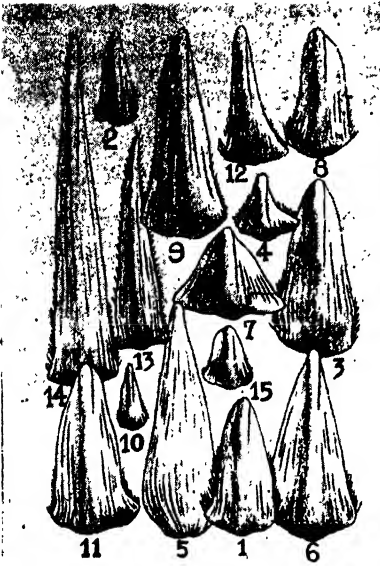


Fig. 3.

Verkümmerte Blattspreiten des Rhizoms:

1. *Phyllostachys nigra*.
2. *Pleioblastus gramineus*.
3. *Pleioblastus Simoni*.
4. *Pleioblastus variegatus*, var. *viridis* f. *glaber*.
5. *Arundinaria variegata*, var. *Tanakae*.
6. *Sasa albo-marginata*.
7. *Sasa septentrionalis*.
8. *Sasaella ramosa*.
9. *Yadakeya japonica*.
10. *Shibatata Kunasasa*.
11. *Semiarundinaria viridis*.
12. *Sinobambusa Tootsik*.
13. *Chimonobambusa marmorata*.
14. *Chimonobambusa quadrangularis*.  $\times 5$ .

Rhizom, das aus der Stengelbasis herauswächst, besitzt an jedem Knoten je eine Knospe, welche sich entweder zum horizontalen Rhizom oder zum aufgerichteten Bambushalm entwickelt.

### Scheidenblätter des Rhizoms.

Die wachsende Spitze des Rhizoms trägt in zwei alternierenden Reihen angelegte Scheidenblätter. Die Form dieser Blätter ist dreieckig oder glockenförmig, an der Spitze tragen sie stets eine verkümmerte Blattspreite (Fig. 2). Letztere ist gewöhnlich dreieckig oder selten rutenförmig, wie z. B. bei *Pleioblastus variegatus*, var. *Tanakae* und *Pleioblastus variegatus*, var. *viridis*, f. *major* (Fig. 3). Im oberen Teil falten sich die Spreiten entlang der Mittellinie mehr oder weniger zusammen, so dass ihr Querschnitt halbmondförmig gekrümmt erscheint (Fig. 1, Taf. I).

## B. ANATOMISCHER AUFBAU DES RHIZOMS.

**Epidermis des Rhizoms.** Die Epidermis der Scheidenblätter besteht aus Lang- und Kurzzellen, Trichomen und Spaltöffnungen. Die Grösse der Langzellen ist je nach den Bambusarten verschieden. Als Trichombildungen treten langgestreckte Stachelhaare am häufigsten auf. Besonders reichlich und sehr kräftig entwickelt sind sie an den Rändern und am Basalteil des Scheidenblattes. Die Spaltöffnungen in der Epidermis



der Aussenseite sind zahlreicher als auf der Innenseite, wobei das Zahlenverhältnis verschieden sein kann.

**Querschnittbilder der Rhizominternodien.** Die äussersten Gefässbündel des Rhizoms rücken im Gegensatz zum gewöhnlichen Stengel von der Epidermis mehr nach innen zu ab, so dass sich dazwischen eine breite Rindenschicht entwickelt. Diese letztere ist ziemlich fest gebaut, und schliesst sich zu einem 1-oder 2-schichtigen subepidermalen Bastmantel zusammen. Nur bei den meisten *Phyllostachys*-Arten besteht die Rinde gewöhnlich aus dickwandigen Zellen, und geht ohne scharfe Abgrenzung in den Bastbelag über (Fig. 2, 3, 4, Taf. I). Die Schutzscheide des Zentralzylinders besteht aus sehr starken, gleichmässig verdickten Zellen, welche entweder voneinander gruppenweise isoliert liegen oder zu einigen isolierten Bastbändern bzw. zu einem echten subcorticalen Bastring verschmelzen können (SHIBATA, '00).

Die einzelnen Gefässbündel des Rhizoms besitzen zwei grosse seitliche Tüpfelgefässe und einige kleine Ring- und Spiralgefässe. Der Siebteil ist gewöhnlich stärker entwickelt als im Stengel. Um die Gefässbündel herum entwickelt sich ein stark verdicktes Sklerenchym. Die Wandverdickung der Sklerenchymzellen beträgt bei *Phyllostachys*-Arten 2.5–5.1  $\mu$ , bei *Pleioblastus*-Arten 1.5–3.5  $\mu$  und bei *Sasa*-Arten 2.5–4.5  $\mu$ .

**Niederblätter des Rhizoms.** Im Querschnitt der Niederblätter erblickt man im farblosen Parenchym parallelverlaufende, abwechselnd stark und schwach entwickelte Gefässbündel. Die Bastbeläge auf der Leptomseite stossen stets unmittelbar an die Epidermis. Den grossen Gefässbündeln gegenüber liegen die kleinen Bündel der Innenseite des Niederblattes an (Fig. 5, Taf. I).

Der Entwicklungsgrad der Hypodermiszellen unter der Epidermis der Aussenseite ist je nach den Bambus-Arten verschieden. Es lassen sich folgende 4 Typen unterscheiden:

- 1) Keine Hypodermis, so z. B. bei *Sasa septentrionalis* (Fig. 6, Taf. I).
- 2) Eine schwach oder stark verdickte einschichtige Hypodermis, wie z. B. bei *Sinobambusa Tootsik* (Fig. 7, Taf. I).

3) Eine schwach verdickte 1–2 schichtige Hypodermis, wie z. B. bei *Shibatata Kumasasa* und *Arundinaria nitakayamensis*.

4) Eine stark verdickte, mehrschichtige Hypodermis, wie z. B. bei *Phyllostachys reticulata*, *f. subvariegata* und *Pleioblastus linearis* (Fig. 8, Taf. I).

**Verkümmerte Blattspreite der Niederblätter.** Die Epidermis der verkümmerten Blattspreite besteht wie beim Scheidenblatt selbst aus Lang- und Kurzzellen, Trichomen und Spaltöffnungen. Als Trichomgebilde treten langgestreckte Stachelhaare häufig auf. Besonders reichlich und sehr kräftig entwickelt sind sie auf der Epidermis der Basis, der Aussenseite, wie auch auf der inneren Seite der Spreite (Fig. 1, Taf. I).

Die Spaltöffnungen sind auf der Aussenseite viel zahlreicher als auf der Innenseite, wo sie nur dem Spreitenrand entlang vorkommen.

Das Mesophyll bildet keine Palisaden; ein farbloses oder mitunter leicht grüngefärbtes Parenchym füllt den ganzen Raum zwischen den beiden Epidermen aus. Aerenchymatisches Parenchym kommt bei einigen Arten vor, wie z. B. bei *Phyllostachys reticulata*, *Phyllostachys nigra*, *var. Henonis*, *Sasa albo-marginata*, *Chimonobambusa quadrangularis*, *Pleioblastus variegata*, *var. viridis*, *f. major* (Fig. 9, Taf. I) u. a. Die Spreite wird von zweierlei Gefässbündeln durchzogen, nämlich grossen primären und zwischen ihnen befindlichen kleinen sekundären. Sämtliche Gefässbündel werden von Basthelägen begleitet; nur die grossen Gefässbündel stossen auf der Leptonseite unmittelbar an die Epidermis (Fig. 1, Taf. I).

### III. DIE WURZEL.

#### A. MORPHOLOGISCHE EIGENSCHAFTEN DER WURZEL.

Die Pfahlwurzel des Bambuskeimlings ist, wie bekannt, kurzlebig; an ihre Stelle treten viele stammbürtige Wurzeln, die an den Knoten der Stengelbasis und des Rhizoms entspringen. An oberirdischen Halmknoten entwickeln sich Wurzeln nur in einigen speziellen Fällen, wie z. B. an erkrankten Stengeln, bei Halmstecklingen und im unteren Teil der Stengel von einigen Arten, wie z. B. von *Dendrocalamus latiflorus*, *Chimonobambusa quadrangularis* (Fig. 4) u. a.

Die Wurzelanlagen an den Knoten der Stengel sind ein- bis mehrreihig angeordnet. Bei den riesengrossen Bambusgewächsen, wie z. B. bei *Dendrocalamus* und *Bambusa*-Arten, werden 7–8 Reihen sprossbürtiger Wurzeln an der Stengelbasis gebildet.

## B. ANATOMISCHER AUFBAU DER WURZELN.

Im Wurzelquerschnitt lassen sich folgende Elemente nachweisen: Epidermis, Rinde und Zentralzylinder. Die direkt unter den Epidermiszellen liegende Exodermis ist stets einschichtig (SHIBATA, '00; KROEMER, '03). Die Exodermiszellen sind bei *Phyllostachys*, *Pleiolblastus*, *Sasa*, *Pseudosasa*, *Semiarundinaria*, *Sinobambusa*, *Shibatata* und *Chimonobambusa* in ihren äusseren und radialen Wänden stark verdickt, während sie bei *Dendrocalamus* und *Bambusa* allseitige Wandverdickungen aufweisen (Fig. 10, Taf. I).

Auf die Exodermis folgt das Sklerenchym, dessen Dicke je nach den Arten verschieden ist. *Dendrocalamus*- und *Bambusa*-Arten weisen 2–5 Schichten von Sklerenchymzellen auf, welche sich von den weiter nach innen hin gelegenen Rindenzellen scharf abheben (Fig. 10, Taf. I). Bei *Semiarundinaria viridis* ist dagegen das Sklerenchym 5–7 schichtig und geht allmählich in die inneren Rindenzellen über (Fig. 11, Taf. I). Die innerste Rindenschicht entwickelt sich zur Endodermis; diese erscheint bei *Dendrocalamus*- und *Bambusa*-Arten infolge der Wandverdickungen als eine charakteristische O-Scheide (SCHWENDENER, '74), während alle übrigen Gattungen eine C-Scheide aufweisen.

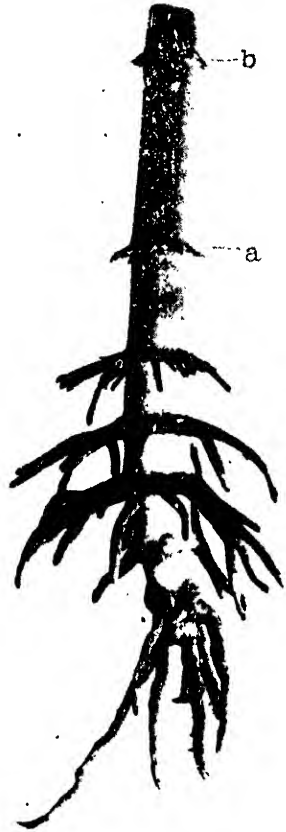


Fig. 4.

Mit Luftwurzeln versehene oberirdische Halmknoten (*Chimonobambusa quadrangularis*), a, b Luftwurzeln.  $\times \frac{1}{2}$ .

Bemerkenswert ist hierbei der Umstand, dass in der Verdickungsweise von Exodermis und Endodermis ein bestimmter korrelativer Zusammenhang existiert: wenn nämlich die Endodermis als C-Scheide ausgebildet ist, so ist auch die Verdickung der Exodermis C-förmig und stets aussenseitig, so dass die beiden Verdickungen einander gegenüberliegen.

#### IV. DER HALM.

##### A. MORPHOLOGISCHE EIGENSCHAFTEN DES HALMS.



Fig. 5.

Stengel mit und ohne scharfe Abgrenzung des echten Stengels von der unterirdischen Halmbasis: 1. *Dendrocalamus latiflorus*, 2. *Semiarundinaria fastuosa*, a Stengelteil, b Unterirdische Halmbasis, c Stiel.  $\times 1/3$ .

##### Gliederung des Halms.

Bei allen Bambushalmen, mit Ausnahme von *Arundinaria niitakayamensis*, stellt die Halmbasis ein kurzes Gebilde dar, dessen Länge nur 1–10 cm., selten 20–30 cm. beträgt. Ich möchte diesen kurzen Teil als „gestauchte Halmbasis“ bezeichnen. Diese gestauchte Halmbasis ist bei einigen Gattungen, wie *Dendrocalamus* (Fig. 5, 1), *Bambusa* und einigen *Sasa*-Arten nach dem Aussehen scharf von dem echten Halm zu unterscheiden, während sie bei anderen Gattungen, wie *Phyllostachys*, *Pseudosasa*, *Pleioblastus* u. a. ohne merkliche Abgrenzung in diesen übergeht (Fig. 5, 2). An der gestauchten Halmbasis,

welche in ihrer Wuchsart ziemlich vom echten Stengel abweicht, lassen sich wiederum zwei Teile unterscheiden, nämlich: 1. die distale angeschwollene Halmbasis mit riesigen Knospen und Wurzelanlagen (Fig. 5 1b), und 2. den schlanken Stiel ohne Knospen und Wurzelanlagen (Fig. 5 1c) (SHIBATA, '00). Die Einteilung eines Bambushalms kann man nach morphologischen Gesichtspunkten folgenderweise durchführen.

- Bambushalm { a. Oberirdischer Halm oder echter Stengel.  
                   b. Unterirdische, gestauchte Halmbasis.<sup>1)</sup>  
                   { 1. Übergangshalm oder Angeschwollene Stengelbasis.  
                   { 2. Stiel oder Verbindungsstück.

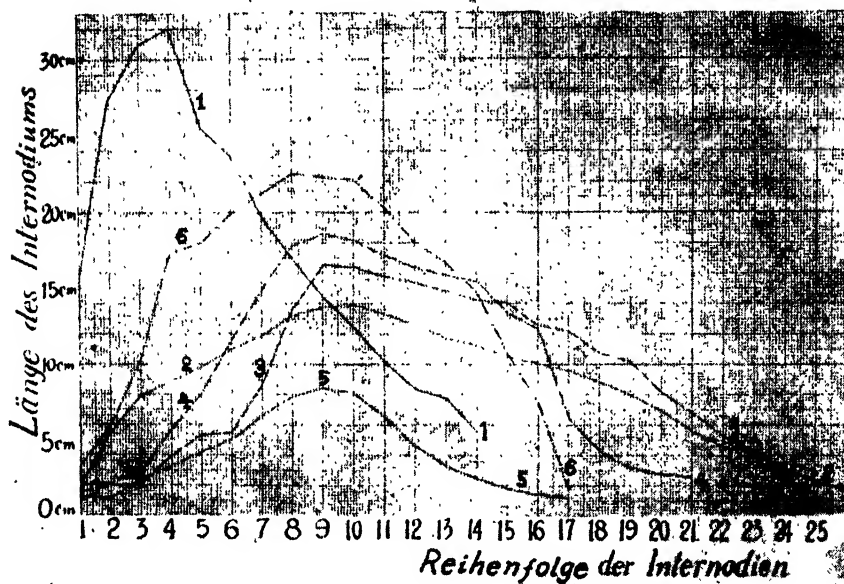


Fig. 6.

Variationskurve der Länge der Internodien des echten Halms:

1. ——— *Bambusa nana*, var. *normalis*.
2. .... *Phyllostachys nigra*.
3. - - - - *Pleioblastus Simoni*.
4. - · - · - *Yadakeya japonica*.
5. — · — · — *Sasa Teuhoiana*.
6. - - - - *Sinobambusa Tootsik*.

1) Diese unterirdische Halmbasis kann mit dem Alter infolge der Rasenbildung oberirdisch werden, wie z. B. bei *Bambusa stenostachya*, dabei bleiben aber die anatomischen Verhältnisse ganz unverändert.

**Halminternodien.** Die Zahl und die Länge der Halminternodien sind natürlich je nach der Art verschieden. Sehr zahlreiche Internodien besitzen *Phyllostachys*-Arten, auch die riesigen *Dendrocalamus*- und *Bambusa*-Arten (mehr als 40–50), während bei *Pleioblastus*, *Sasa*, *Yadakeya* und anderen kleinen Bambus-Arten oft nur 15–20 Internodien vorhanden sind. Die Länge der Internodien nimmt gewöhnlich von unten bis zum mittleren Teil des Halmes zu, um dann wieder abzunehmen, wie es die gegebenen Kurven veranschaulichen in Fig. 6.

Die Variationskurven, welche die Längenverhältnisse der Internodien des echten Halmes illustrieren, lassen sich der Hauptsache nach in 3 Typen einteilen, nämlich: 1) Kurven mit schnell auf- und etwas langsamer absteigendem Verlauf innerhalb relativ enger Grenzen (*Bambusa* u. a.). 2) Kurven mit mehr oder minder symmetrischem Verlauf (*Sinobambusa* u. a.), und 3) Kurven mit sehr langsam auf- und absteigendem Verlauf (*Phyllostachys* u. a.).

Der Durchmesser der Halminternodien nimmt von unten nach oben allmählich ab, während ihr Lumen in der mittleren Halmregion seinen maximalen Wert erreicht und von dort nach oben wie unten hin abnimmt.

**Halmknoten.** Jeder Knoten besitzt gewöhnlich eine Knospe (Fig. 7), welche jedoch an den unteren Knoten manchmal fehlt. Die Länge der Knoten zeigt dem Halm entlang keine bedeutenden Unterschiede, wenngleich die Knoten der mittleren Halmpartie verhältnismässig mehr in die Länge gestreckt sind.

**Verdickungsweise der Internodienbasis.** An der Basis jedes Internodiums liegt die wachstumsfähige Partie. Hat das Wachstum des Internodiums aufgehört, so entsteht in der Wand dieser Partie eine Anschwellung nach aussen wie nach innen. Wenn die Hervor-



Fig. 7.

Stengelstück von *Pleioblastus variegata*, var. *viridis*, f. *b. glabra*. k Knoten, i Internodium,  $\times 1$ ,

wölbung stark nach aussen geht, dann ist die Verdickung nach innen nur schwach, so z. B. bei *Phyllostachys* u. a. Umgekehrt verhält es sich bei *Bambusa*, *Pleiolblastus*, *Pseudosasa* u. a. (Fig. 8).

## B. ANATOMISCHER AUFBAU DES HALMES.

**Epidermis der Stengelbasis.** Die Epidermiszellen der Stengelbasis und des Stiels sind in der Oberflächenansicht sehr verschieden. Auf

dem Stiel sind die Epidermiszellen mehr oder weniger rechteckig, während sie an der Stengelbasis ganz unregelmässige Umrisse besitzen.

Die relative Zahl der Spaltöffnungen ist in diesen beiden Teilen nicht immer dieselbe; bei vielen Arten sind sie zahlreicher an der Halmbasis als auf dem Stiel, während sie bei einigen anderen ungefähr gleich zahlreich sind; auch das umgekehrte Verhältnis kann vorkommen.

**Gefässbündel der Stengelbasis.** Die Querschnittform der Gefässbündel mit Bastbelägen ist in der gestauchten Halmbasis und im Stiel sehr verschieden. In letzterem sind die Gefässbündel vollkommen von Bastzellen umgeben und das Hadrom besteht aus nur einem (seltener zwei) grossen Gefäss (Fig. 9 a), während in der Halmbasis die zwei Gefässe führenden Bündel mit ein- oder zweiseitig angelegten Bastbelägen versehen sind (Fig. 9 b) (DE BARY, '84; MOLISCH, '22; HABERLANDT, '24).

Die Rinde der gestauchten Zweigbasis und des Stiels besteht aus etwa 20 Schichten parenchymatischer Zellen. Die Bastbeläge der



Fig. 8.

Halbknoten von verschiedenen Arten:

1. *Phyllostachys reticulata*, var. *aurea*.
2. *Phyllostachys nigra*.
3. *Bambusa nana*, var. *normalis*.
4. *Pleiolblastus Simoni*.
5. *Shitataea Kunasasa*.
6. *Yulakea japonica*.  $\times \frac{2}{3}$ .

äussersten Bündel verschmelzen in diesen beiden Teilen zu einem unterbrochenen oder einheitlichen Band.

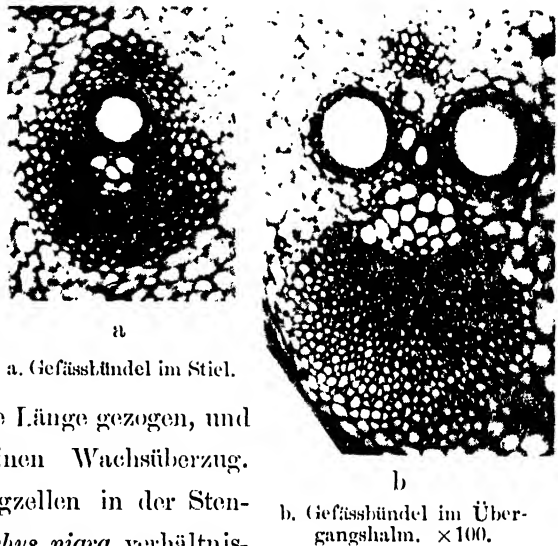
### Epidermis des Halmes.

Die Halmepidermis besteht aus Lang- und Kurzzellen, Trichomen und Spaltöffnungen. Die Langzellen sind gewöhnlich in die Länge gezogen, und besitzen in der Regel einen Wachsüberzug. Länge und Breite der Langzellen in der Stengelmittle sind bei *Phyllostachys nigra* verhältnismässig gering ( $0.041\text{mm} \times 0.007\text{mm}$ ), bei *Yadakeya japonica* ( $0.098\text{mm} \times 0.012\text{mm}$ ) und *Semiarundinaria fastuosa* ( $0.105\text{mm} \times 0.013\text{mm}$ ) dagegen sehr gross. Die Spaltöffnungen sind am Stengel in der Regel spärlich, bei einigen Arten aber können sie etwas häufiger sein, wie das bei *Bambusa nana*, var. *normalis*, f. *Alphonso-Karri* (336 per  $\text{mm}^2$ ), *Chimonobambusa marmorea* (96 per  $\text{mm}^2$ ) und *Arundinaria nitakayamensis* (33 per  $\text{mm}^2$ ) der Fall ist.

**Gefässbündel der Halme.** Die Gefässbündel der Halme sind auf dem Querschnitt zerstreut angeordnet; die äusseren sind immer kleiner, die inneren grösser. Die kleinen peripheren Gefässbündel, die innerhalb des sklerotisch verdickten 1–2 schichtigen Rindenparenchyms liegen, sind von Bastbelägen umgeben. Bei vielen Bambuseen verschmelzen die Bastbeläge und die dazwischen liegenden Baststränge nicht miteinander; bei einigen Arten aber verschmelzen die Bastbeläge seitlich mit einander von Bündel zu Bündel, so dass ein ganz geschlossener Bastring zustandekommt, wie dies bei *Sasa nipponica* u. a. der Fall ist.

Das einzelne Gefässbündel ist kollateral gebaut und durch zwei grosse Tüpfelgefässe und ein Spiralgefäss ausgezeichnet (Fig. 10, 2.), mit Ausnahme von *Dendrocalamus* und *Bambusa*, welche zwischen den beiden grossen Tüpfelgefässen noch ein oder zwei Paare kleiner Spiral-

Fig. 9.  
Gefässbündeltypen:





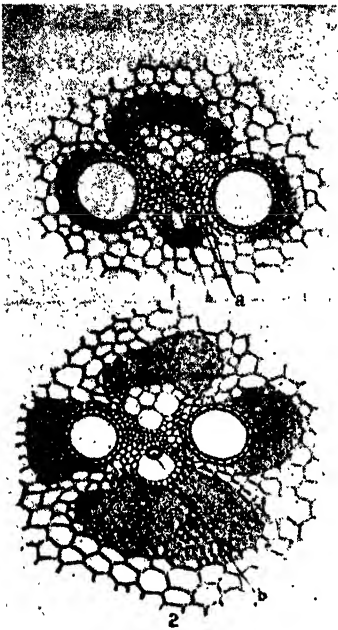


Fig. 10.

Gefässbündel von: 1. *Bambusa nana*, var. *normalis*, f. *Alphonso-Karri*, und 2. *Phyllostachys Makinoi*; a und b Spiralgefässe.  $\times 50$ .

HABERLANDT, '79).

Die Gefässbündel der Knoten zeigen auf dem Querschnitt Queranastomosen. Es gibt zwei Formen von Gefässbündeln, je nachdem 1. die Bastbündel die Gefässbündel ringsum in Form einer festen Scheide umschliessen, oder 2. ein oder zweiseitig halbmondförmig angelegt sind, wie in der gestauchten Halmbasis.

Die äussersten, kleinen Bastbündel der Internodien-

gefässe aufweisen (Fig. 10, 1) (KANEHIRA, '26).

Die Gefässbündel sind in dünnwandigem Parenchym eingebettet und werden auf vier Seiten von Bastbelägen begleitet. Bei einigen Bambusarten, wie z. B. *Dendrocalamus*- und *Bambusa*-Arten, *Pleioblastus Hindsi* und *Chimonobambusa quadrangularis* sind die Bastbeläge an der Innenseite mit eigentümlichen Parenchymzellen versehen (SCHWENDENER, '74;

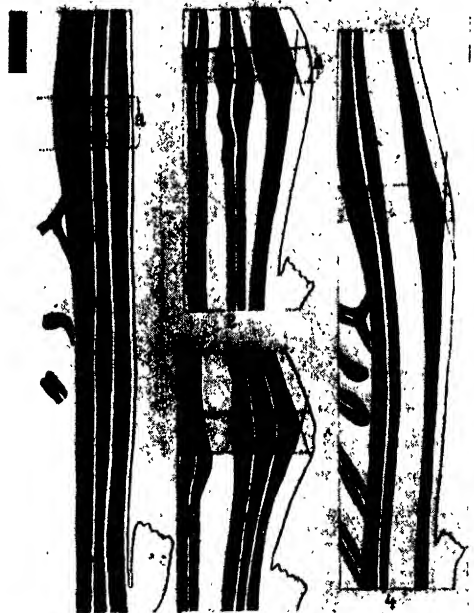


Fig. 11.

Krümmungsweise der Bastbündel in der Internodienbasis des Stengels:

1. *Yadakeya japonica*.
2. *Sasa albo-marginata*.
3. *Phyllostachys nigra*, var. *Henonis*.
4. *Pleioblastus Hindsi*.
- a. Internodienbasis.  $\times 8$ ,

basis des Halms sind in der Längsrichtung, je nach der Bambusart, mehr oder minder nach auswärts gekrümmt (Fig. 11). Die Krümmungswinkel in den mittleren Internodien der Stengel sind in folgender Tabelle zusammengestellt:

TABELLE I.

Krümmungswinkel der äussersten Bastbündel der Internodienbasis.

<i>Bambusa nana</i> , var. <i>normalis</i> .	175°	<i>Pleiblastus variegata</i> , var. <i>viridis</i> , f.	
<i>B. Oldhami</i> .	165°	<i>major</i> .	156°
<i>Phyllostachys nigra</i> .	134°	<i>Arundinaria nitakayamensis</i> .	169°
<i>P. nigra</i> , var. <i>Henonis</i> .	121°	<i>Sasa albo-marginata</i> .	150°
<i>P. nigra</i> , var. <i>Henonis</i> , f. <i>Boryana</i> .	147°	<i>S. australis</i> .	138°
<i>P. reticulata</i> .	145°	<i>S. nipponica</i> .	138°
<i>P. reticulata</i> , var. <i>Marliacea</i> .	144°	<i>S. septentrionalis</i> .	158°
<i>Pleiblastus Chino</i> .	160°	<i>S. Tokugawana</i> .	154°
<i>P. Chino</i> , var. <i>Laydekeri</i> .	150°	<i>S. Tsuboiana</i> .	160°
<i>P. graminea</i> .	164°	<i>Sasaella iwatekensis</i> .	147°
<i>P. Hindsii</i> .	162°	<i>S. matsusimensis</i> .	145°
<i>P. Kiusianus</i> .	153°	<i>S. ramosa</i> .	155°
<i>P. linearis</i> .	160°	<i>Pseudosasa Kurilensis</i> , var. <i>nebulosa</i> .	174°
<i>P. Simoni</i> .	150°	<i>P. spiculosa</i> .	176°
<i>P. Usawai</i> .	156°	<i>Yadakeya japonica</i> .	175°
<i>P. variegata</i> .	158°	<i>Shibataea Kumasasa</i> .	144°
<i>P. variegata</i> , var. <i>Akebono</i> .	168°	<i>Semiarundinaria fastuosa</i> .	164°
<i>P. variegata</i> , var. <i>pygmaea</i> , f.		<i>S. viridis</i> .	159°
<i>glabra</i> .	165°	<i>Sinobambusa Tootsik</i> .	130°
<i>P. variegata</i> , var. <i>Tanakae</i> .	164°	<i>Chimonobambusa marmorea</i> .	162°
<i>P. variegata</i> , var. <i>viridis</i> , f. <i>glabra</i> .	156°	<i>C. quadrangularis</i> .	150°

**Struktur des Diaphragmas.** Das Grundgewebe der Diaphragmen besteht aus getüpfelten, mehr oder weniger vieleckigen oder elliptischen Parenchymzellen, welche eine dichte Gewebeplatte bilden.

Bei den kleinen Bambus-Arten befindet sich im Zentrum des Diaphragmas ein Aerenchym (Fig. 6, Taf. II), dessen Zellen stets reihenweise in der Längsrichtung übereinander liegen, so dass dadurch den Zellkanten entlanglaufende Luftkanäle zustandekommen, wie z. B. bei *Sasa*, *Pleiblastus* u. a. (Fig. 1 u. 2, Taf. II).

Bei den meisten Bambusarten bestehen aber die oberen und die unteren Schichten des Diaphragmas aus stark getüpfelten, dickwandigen Brachysklereiden. Sie sind zweieckig oder seltener rechteckig. Bei den meisten Arten sind die Brachysklereiden unregelmässig angeordnet (Fig. 3 u. 5, Taf. II); eine Ausnahme bildet *Arundinaria nitakayamensis*, bei der die genannten Zellen reihenweise angeordnet sind (Fig. 4, Taf. II). Bisweilen finden sich unter den dickwandigen Zellen vereinzelt oder gruppenweise dünnwandige, getüpfelte Parenchymzellen, so z. B. bei *Yalakeya japonica* (Fig. 3, Taf. II).

## V. DIE BLATTGEBILDE.

### A. MORPHOLOGISCHE EIGENSCHAFTEN DER BLATTGEBILDE.

**Blattscheide.** Das Blatt der Bambuseen besteht in der Hauptsache aus Blattscheide und Blattspreite, die durch einen kurzen Blattstiel verbunden sind.

Die Blattscheide dient besonders dem Schutz und der Festigung des noch jungen, weichen Halmes. Bei einigen Gattungen, wie z. B. *Phyllostachys*, *Bambusa*, *Semiarundinaria* u. a., erfolgt die Abstossung der Scheide schon im jugendlichen Zustand des Internodiums, während bei anderen Gattungen die Scheiden lang erhalten bleiben und den Stengel noch umhüllen wenn dieser schon längst ausgewachsen ist.

**Blattspreite.** Die Blattspreite ist in der Jugend gerollt, wie im allgemeinen bei den Gramineen. Auf dem Querschnitt erscheint die Spreite spiralig eingerollt (TSCHIRCH, '82), wobei der eine Seitenabschnitt der Spreite über den andern hinübergreift, und zwar so, dass das Endstück des übergreifenden Teils weniger gewölbt ist als das des eingeschlossenen (Fig. 12).

Die Spreite ist meist lanzettförmig, sehr selten schmal; letzteres ist z. B. bei *Pleiblastus gramineus*, *Pleiblastus variegatus* u. a. der Fall. Kurzlanzettliche Spreiten sind nur bei wenigen Arten zu sehen

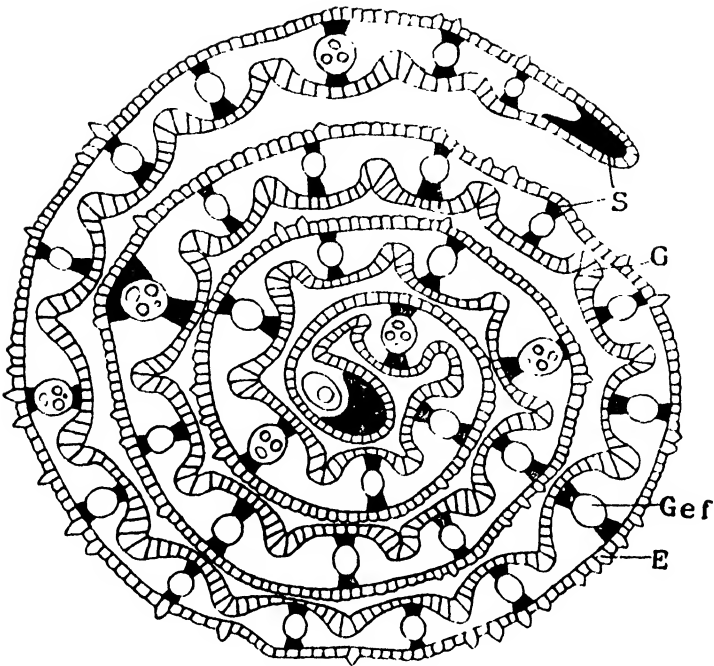


Fig. 12.

Junge e'ngerollte Blattspreite von *Phyllostachys edulis*, var. *heterocycla*;  
E Epidermis, G Gelenkzellen, S Stereome, Gef. Gefäßbündel.  $\times 130$ .

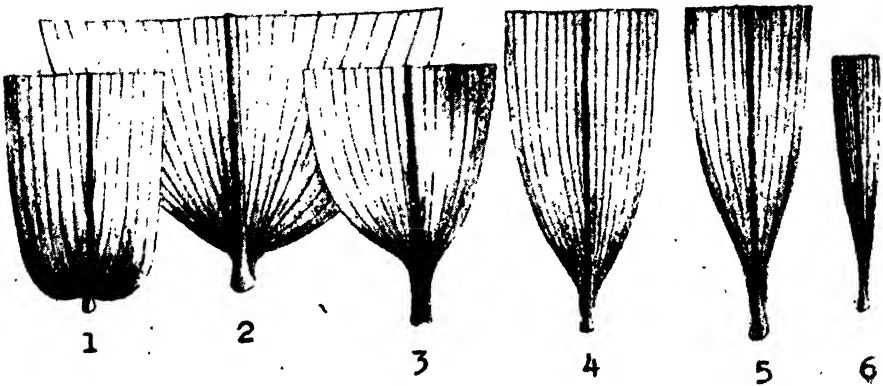


Fig. 13.

Typen der Spreitenbasis:  $\times 1$ .

- |                                   |                                      |                                    |
|-----------------------------------|--------------------------------------|------------------------------------|
| 1. <i>Bambusa Oldhami</i> .       | 2. <i>Dendrocalamus latiflorus</i> . | 3. <i>Sasa nipponica</i> .         |
| 4. <i>Phyllostachys Makinoi</i> . | 5. <i>Yadakeya japonica</i> .        | 6. <i>Pleioblastus variegata</i> . |

(*Dendrocalamus latiflorus*, *Pseudosasa Kurilensis*, var. *nebulosa*, *Shibataea Kumasasa* u. a.).

Der basale Umriss jeder Spreite hängt mit ihrer Lage am Halm zusammen. Das unterste Blatt ist oft von den übrigen abweichend gebaut, so namentlich bei *Bambusa Oldhami*; *Sasa Tokugawana* u. a., wo der Umriss der Spreitenbasis der unteren Blätter rundlich ist und in den oberen Blättern allmählich zugespitzt wird. Die Form der Spreitenbasis ist bei *Dendrocalamus latiflorus* und *Bambusa Oldhami* rundlich, bei *Phyllostachys Makinoi*, *Sasa nipponica* und *Yadakeya japonica* allmählich zugespitzt, und bei *Pleioblastus variegata* (Fig. 13) ganz schmal zugespitzt.

Die Spreitenspitzen haben mannigfaltige Formen. Bei *Pleioblastus gramineus* und *Pleioblastus variegatus* sind sie annähernd lineal, während sie bei andern Arten, wie z. B. *Pleioblastus Chino*, var. *viridis*, f. b. *glabra*, *Shibataea Kumasasa* u. a. meist kurz zugespitzt sind (Fig. 14).

Luftgänge in den Blattspreiten, welche bei den meisten *Sasa*-Arten, *Dendrocalamus latiflorus*, *Yadakeya japonica* u. a. so häufig auftreten, fehlen bei den meisten *Phyllostachys*-Arten, *Arundinaria nitakayamensis* u. a.

**Blatthäutchen.** Am Grunde der kurzgestielten Blattspreite setzt

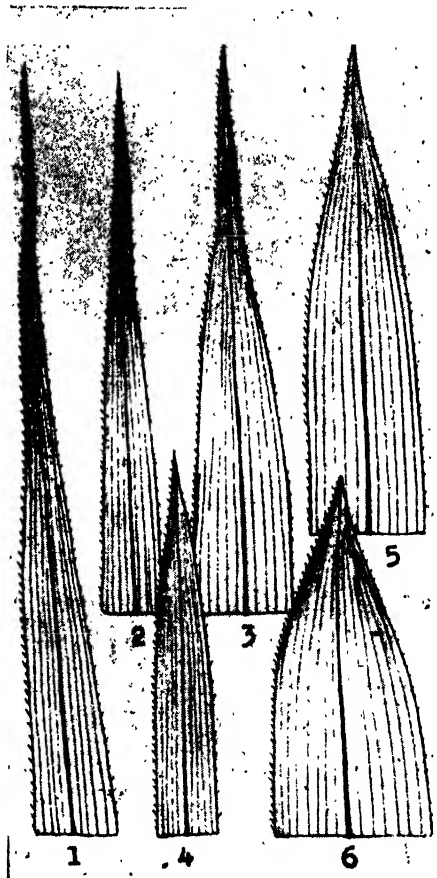


Fig. 14.

Typen der Blattspreite:

1. *Pleioblastus gramineus*.
2. *Pleioblastus variegata*.
3. *Chimonobambusa quadrangularis*.
4. *Pleioblastus Chino*, var. *Laydekeri*.
5. *Pleioblastus variegata*, var. *viridis*, f. b. *glabra*.
6. *Shibataea Kumasasa*. × 1.

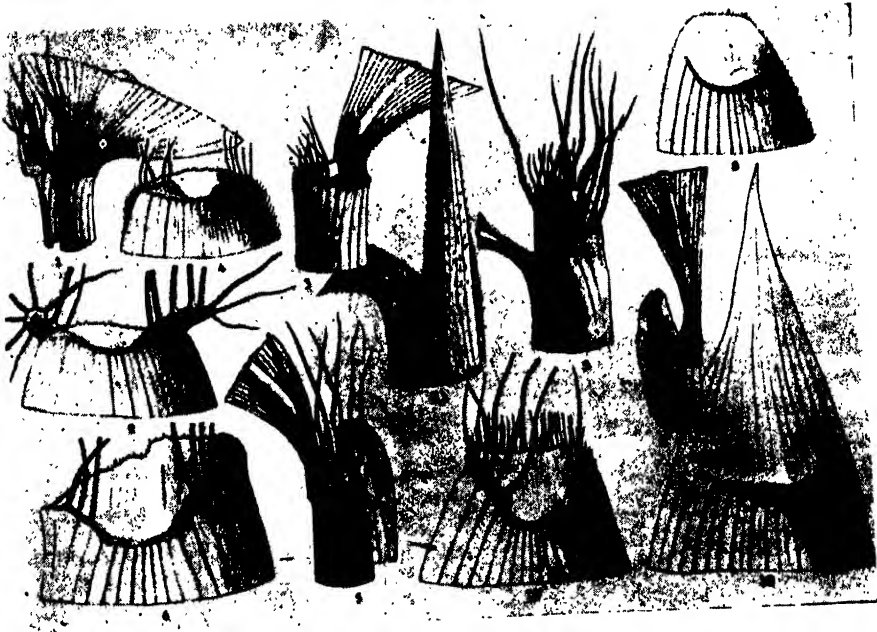


Fig. 15.

Typen der Blatthäutchen:  $\times 8$ .

- |           |                                 |            |                              |
|-----------|---------------------------------|------------|------------------------------|
| 1. u. 2.  | <i>Bambusa Shimadai.</i>        | 3. u. 4.   | <i>Sasa Tsuboana.</i>        |
| 5. u. 6.  | <i>Pleioblastus variegata.</i>  | 7. u. 8.   | <i>Phyllostachys edulis.</i> |
| 9. u. 10. | <i>Phyllostachys formosana.</i> | 11. u. 12. | <i>Shibataea Kumasasa.</i>   |

sich die Scheide in ein häutiges Blatthäutchen (Ligula) fort, welches durch nachträgliches Wachstum der Blattscheide entstanden ist (ENGLER u. PRANTL, '87). Die Form der Ligula ist bei *Bambusa*, *Sasa*, *Sinobambusa* und *Chimonobambusa* kreisbogenförmig (Fig. 15), während sie bei anderen Gattungen, wie z. B. *Pleioblastus*, *Semiarundinaria* und *Pseudosasa* auf den zwei Seiten in ungleicher Stärke ausgebildet ist (Fig. 15). Eine ähnliche Asymmetrie kommt auch bei *Phyllostachys* vor, wo der Rand aber mehr oder minder kantig ist (Fig. 15). Eine sonderbar ausgebildete Ligula (meist scharf zugespitzt und dreieckig) tritt bei der Gattung *Shibataea* auf (Fig. 15).

**Öhrchen.** An der Trennungsstelle zwischen Blattstiel und Scheide finden wir ausser der Ligula ein eigentümliches knorpeliges Öhrchen, welches je nach der Spezies schwach oder stark entwickelt sein kann (VELENOVSKY, '07). Bei der Gattung *Bambusa* ist dieses Öhrchen immer

lang ausgezogen und mit langen Börstchen besetzt (Fig. 15). Auch bei *Phyllostachys*, *Pleioblastus*, *Pseudosasa*, *Semiarundinaria*, *Sinobambusa*, *Chimonobambusa* und einigen *Sasa*-Arten ist das Öhrchen ziemlich stark ausgebildet (Fig. 15), wogegen es sich bei *Dendrocalamus latiflorus* und einigen *Sasa*-Arten nur zu unbedeutlicher Länge entwickelt.

**Verkümmerte Blattspreiten der Bambus-Schösslinge.** Am Ende jedes Scheidenblattes der Bambus-Schösslinge befindet sich eine verkümmerte Blattspreite. Verfolgt man die Blattspreiten an einem Schössling von unten nach oben, so finden wir, dass ihre Form und Grösse von der untersten rudimentären Spreite angefangen eine allmähliche Umwandlung erfährt, bis wir schliesslich eine vollkommene Blattspreite erreichen, welche der art eigenen Blattform entspricht (Fig. 16). Die folgenden Zahlen sind bei zwei Spezies, deren jede einen eigenen Typus vorführt, festgestellt worden.

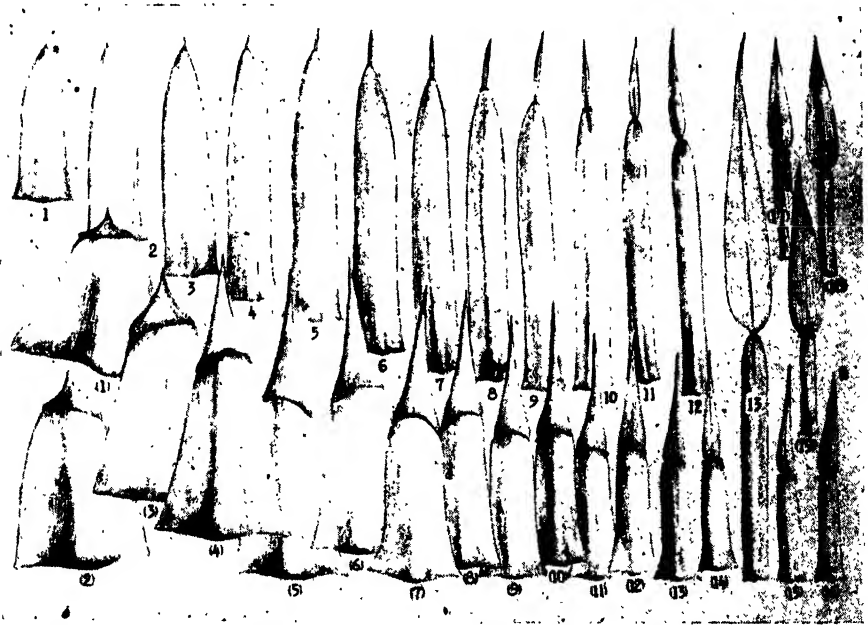


Fig. 16.

Übergangsformen der Blattspreite von der verkümmerten bis zur normalen:  $\times \frac{1}{3}$ .

1-13. *Yadakeya japonica*.

(1)-(19) *Bambusa pachinensis*.

TABELLE II. Länge und Breite der verkümmerten Blattspreiten von Schösslingen.

<i>Yadakeya japonica</i>				<i>Bambusa nana, var. normalis</i>				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Breite (cm.)	Länge (cm.)	Mittlerer Teil	Bassteil	Breite (cm.)	Länge (cm.)	Mittlerer Teil	Bassteil	Länge (cm.)																		
								1.6	2.4	3.3	5.8	7.5	7.7	7.1	6.7	6.6	7.0	6.5	6.5	6.1	6.1	6.3	5.9	6.5	7.8	9.7
0.05	0.25	0.05	0.07	0.05	0.3	0.35	0.9	1.3	1.95	2.7	3.1	3.8	4.2	4.8	6.4	17.0										
0.07	0.08	0.1	0.1	0.1	0.11	0.11	0.12	0.12	0.15	0.15	0.2	0.32														

Wie die Tabelle zeigt, lassen sich die verkümmerten Blattspreiten nach ihrer Form in zwei Typen einteilen: 1. Bei *Dendrocalamus* und *Bambusa* ist die verkümmerte Blattspreite im mittleren Teil des Schösslings dreieckig, 2. bei den übrigen Gattungen aber ist sie schmal-lanzettförmig.

Die verkümmerten Blattspreiten sind bei den Gattungen *Dendrocalamus*, *Bambusa*, *Shibataea*, *Chimonobambusa* u. a. hellbraun, bei den übrigen sind sie gewöhnlich grün gefärbt.

Die Luftgänge im Parenchym, die in den Blattspreiten zumeist vorhanden sind, sind in den verkümmerten Blattspreiten schwach oder gar nicht entwickelt.

## B. ANATOMISCHER AUFBAU DER BLATTGEBILDE.

**Epidermis des Scheidenblattes.** Die Epidermis der Aussenseite des Scheidenblattes besitzt beim Schössling häufig verdickte Zellwände und trägt oft Lang-



oder Kurzstachelhaare. Diese Haare entwickeln sich meistens nur auf den Rippen und haben eine schief aufwärts gerichtete Stellung. Bei den meisten Arten sind über dem Parenchym Winkelhaare entwickelt. Sie sind stets zweizellig und ihre Richtung ist ganz regellos. Die Epidermis der Innenseite ist stets dünnwandig und bildet eine glatte und glänzende Oberfläche, die keine Haare besitzt. Spaltöffnungen kommen nur auf der Aussenseite vor, wo sie regelmässig in Längsreihen zwischen je zwei Langzellenreihen liegen. Die Zahlen der Trichome und Spaltöffnungen auf der Epidermis der Aussenseite sind in der folgenden Tabelle zusammengestellt.

TABELLE III.

Zahlen der Trichome und Spaltöffnungen auf der Epidermis der Aussenseite des Scheidenblattes.

Namen	Spaltöffnungen (per mm <sup>2</sup> )	Trichome (per mm <sup>2</sup> )		
		Stachelhaare		Zweizellige Winkelhaare
		Langgestreckte Stachelhaare	Kurze Stachelhaare	
<i>Bambusa nana.</i>	108	0	0	28
<i>B. pachinensis.</i>	56	0	0	24
<i>B. stenostachya.</i>	52	8	116	0
<i>Phyllostachys edulis.</i>	48	2	0	0
<i>Pleioblastus Chino.</i>	68	0	0	12
<i>P. Chino,</i> <i>var. argenteo-striata.</i>	48	0	0	0
<i>P. gramineus.</i>	72	0	0	16
<i>P. linearis.</i>	36	0	0	28
<i>P. Matsunoi.</i>	48	0	112	20
<i>P. Simoni.</i>	36	4	0	24
<i>P. Usawai.</i>	44	0	0	0
<i>P. variegatus.</i>	56	0	0	16
<i>P. variegatus,</i> <i>var. Akebono.</i>	36	0	0	24

TABELLE III. — (Fortsetzung)

Namen	Spaltöffnungen (per mm <sup>2</sup> )	Trichome (per mm <sup>2</sup> )		
		Stachelhaare		Zweizellige Winkelhaare
		Langgestreckte Stachelhaare	Kurze Stachelhaare	
<i>P. variegatus</i> , var. <i>pygmaeus</i> , f. <i>glaber</i> .	60	0	0	8
<i>P. variegatus</i> , var. <i>Tanakae</i> .	64	0	0	12
<i>P. variegatus</i> , var. <i>viridis</i> , f. <i>humilis</i> .	32	0	8	12
<i>P. variegatus</i> , var. <i>viridis</i> , f. <i>major</i> .	60	0	0	16
<i>Arundinaria</i> <i>nitakayamensis</i> .	44	0	0	36
<i>Sasa albo-marginata</i> .	56	0	0	4
<i>S. nipponica</i> .	28	0	0	0
<i>S. septentrionalis</i> .	64	0	0	20
<i>S. Tokugawana</i> .	52	116	0	8
<i>S. Tsuboiana</i> .	48	0	0	4
<i>Sasaella ramosa</i> .	36	0	0	0
<i>P. kurilensis</i> , var. <i>nebulosa</i> .	36	0	0	24
<i>Yadakeya japonica</i> .	20	1	128	16
<i>Shibataea Kumasasa</i> .	16	0	112	8
<i>Sinobambusa Tootsik</i> .	64	0	0	28
<i>Chimonobambusa</i> <i>quadrangularis</i> .	28	0	0	272

**Luftgänge des Scheidenblattes.** Bei den Arten, welche die Scheiden im jugendlichen Zustand des Halmes abstossen, sind diese durch das häufige Vorkommen von grösseren Luftgängen zwischen den Gefässbündeln ausgezeichnet, während bei den Arten, deren Scheiden für längere Zeit erhalten bleiben, gewöhnlich keine Luftgänge sichtbar sind.

**Epidermis der Blattspreite.** Die Epidermis der Blattspreite besteht aus Lang- und Kurzzellen, Spaltöffnungen und Trichomen (PFITZER, '70; GROB, '96; BRANDIS, '07). Die Spaltöffnungen haben einen eigentümlichen Bau, wie schon SCHWENDENER ('81 u. '89) erkannt hat. Sie

sind meistens auf die Unterseite der Blätter beschränkt, nur selten finden sich einige sehr wenige Stomata auch auf der Oberseite der Blattspreite.

Als Trichombgebilde treten die kurzspitzigen Stachelhaare am häufigsten auf (BROCKMANN-JEROSCH, '14, STANDERMANN, '24). Besonders reichlich sind sie an den Blatträndern sowie auf der Unterseite der Blattspreite vorhanden; dagegen treten Stachelhaare auf den Rippen der Blattunterseite seltener auf und sind dann lang zugespitzt (Fig. 17). An den Rändern sind die Stachelhaare, je nach der Bambusart, entweder dicht oder spärlich

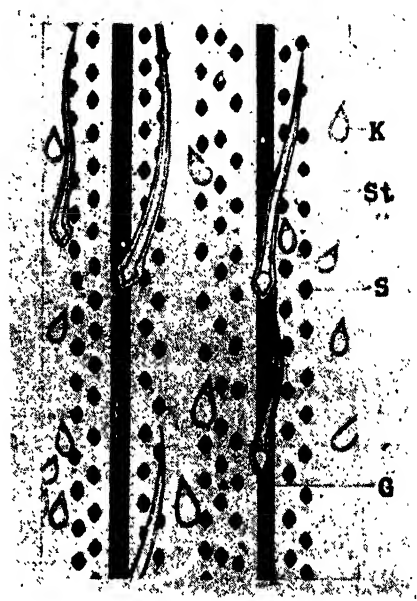


Fig. 17.

Epidermis von *Bambusa dolichoclada* (Schematisch dargestellt). K Kurzes Stachelhaar, L Langgestrecktes Stachelhaar, S Spaltöffnung, G Gefäßbündelstreifen.  $\times 132$ .

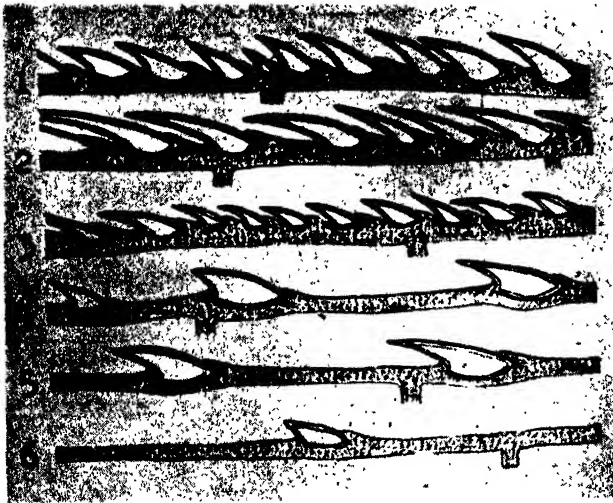


Fig. 18.

 $\times 29$ .

Stachelhaare an den Blatträndern von *Bambusa dolichoclada*: 1-3. Übergreifender Saum, 4-6. Eingeringelter Saum, 1, 4. Oberer Teil, 2, 5. Mittelteil, 3, 6. Basalteil.

vorhanden. Selbst an derselben Spreite sind sie meistens klein und zugespitzt gegen die Spitze und die Mitte der Spreite; an der Basis nehmen sie an Länge zu und entwickeln sich zu langgestreckten Stachelhaaren, so z. B. bei *Bambusa stenostachya*, *Pleioblastus Simoni*, *Sasa albo-*

*marginata* u. a. Im allgemeinen sind die Stachelhaare an den zwei Rändern der Spreite nicht gleich zahlreich. Der in der Jugend übergreifende Saum der gerollten Blattspreite ist weniger oder gar nicht behaart im Gegensatz zu dem eingeschlossenen (Fig. 18). Bei *Dendrocalamus latiflorus* sind aber die Haare an den beiden Rändern nahezu gleich zahlreich. Die Zahlen der Spaltöffnungen und Trichome auf den Blattspreiten sind in der folgenden Tabelle zusammengestellt.

TABELLE IV.

Zahlen der Trichome und Spaltöffnungen auf Ober- und Unterseite der Blattspreiten.

Namen.	Spaltöffnungen (per mm <sup>2</sup> )		Trichome (per mm <sup>2</sup> )			
			Kurze Stachelhaare		Langgestreckte Stachelhaare	
	Oberseite	Unterseite	Oberseite	Unterseite	Oberseite	Unterseite
<i>Dendrocalamus latiflorus</i> .	52	132	0	576	0	0
<i>Bambusa dolichoclada</i> .	0	640	0	16	0	28
<i>B. dolichomerithalla</i> .	0	472	0	104	0	12
<i>B. nana</i> .	0	540	0	16	0	2
<i>B. nana</i> , var. <i>normalis</i> .	0	616	0	184	0	0
<i>B. nana</i> , var. <i>normalis</i> , f. <i>Alphonso-karri</i> .	0	748	0	0	0	32
<i>B. Oldhami</i> .	0	656	0	128	0	0
<i>B. pachinensis</i> .	0	644	0	36	0	12
<i>B. stenostachya</i> .	0	596	0	116	0	0
<i>B. Shimadai</i> .	0	496	0	60	0	24
<i>Phyllostachys edulis</i> .	0	760	0	388	0	0
<i>P. edulis</i> , var. <i>heterocycla</i> .	0	680	0	460	0	0
<i>P. edulis</i> , var. <i>heterocycla</i> , f. <i>subconveza</i> .	0	472	0	0	0	0
<i>P. formosana</i> .	0	440	0	332	0	0
<i>P. Makinoi</i> .	0	629	44	448	0	0
<i>P. nigra</i> .	0	608	0	0	0	0
<i>P. nigra</i> , var. <i>Henonis</i> .	0	652	0	216	0	0
<i>P. reticulata</i> .	0	572	0	280	0	0
<i>P. reticulata</i> , var. <i>aurea</i> .	0	548	0	344	0	0
<i>P. reticulata</i> , var. <i>Martianea</i> .	0	608	0	490	0	0

TABELLE IV. — (Fortsetzung)

Namen.	Spaltöffnungen (per mm <sup>2</sup> )		Trichome (per mm <sup>2</sup> )			
			Kurze Stachelhaare		Langgestreckte Stachelhaare	
	Oberseite	Unterseite	Oberseite	Unterseite	Oberseite	Unterseite
<i>Pleioblastus Chino</i> , var. <i>argenteo-striata</i> .	0	336	0	0	0	6
<i>P. gramineus</i> .	0	436	0	136	0	0
<i>P. linearis</i> .	0	376	192	292	0	0
<i>P. Matsunoii</i> .	0	436	0	136	0	0
<i>P. Simoni</i> .	9	524	44	192	0	0
<i>P. Usawai</i> .	0	336	0	248	0	20
<i>P. variegatus</i> .	12	392	0	60	0	0
<i>P. variegatus</i> , var. <i>Akebono</i> .	0	560	0	8	0	0
<i>P. variegatus</i> , var. <i>pygmaeus</i> , f. <i>glabrer</i> .	0	480	0	0	0	0
<i>P. variegatus</i> , var. <i>viridis</i> , f. <i>humilis</i> .	0	324	0	0	2	10
<i>P. variegatus</i> , var. <i>viridis</i> , f. <i>major</i> .	28	424	184	16	0	0
<i>Arundinaria</i> <i>nitakayamensis</i> .	0	316	0	304	0	0
<i>Sasa albo-marginata</i> .	0	520	0	4	0	0
<i>S. nipponica</i> .	0	420	0	0	0	12
<i>S. septentrionalis</i> .	0	580	0	84	0	0
<i>S. Teuboiانا</i> .	8	560	0	420	0	0
<i>Sasaella ramosa</i> .	0	308	0	0	0	12
<i>Pseudosasa kurilensis</i> , var. <i>nebulosa</i> .	0	552	0	192	0	0
<i>Yadakeya japonica</i> .	24	372	0	140	0	0
<i>Shibataea Kumasasa</i> .	0	440	0	20	0	12
<i>Semiarundinaria</i> <i>fastuosa</i> .	8	348	0	192	0	0
<i>S. fastuosa</i> , var. <i>viridis</i> .	20	440	0	252	0	0
<i>S. viridis</i> .	0	624	224	84	0	32
<i>Sinobambusa Tootsik</i> .	0	312	0	288	0	0
<i>Chimonobambusa</i> <i>marmorea</i> .	0	408	0	68	0	0
<i>C. quadrangularis</i> .	0	424	0	0	0	0

**Mesophyll.** Das Mesophyll besteht aus Parenchym, Gefässbündeln und Stereomen (HABERLANDT, '82; GÜNTZ, '86; SCHWENDENER, '20). Im Parenchym lassen sich das farblose Parenchym und die grünen Armpalisadenzellen unterscheiden (KARELTSCHIKOFF, '68; MAGNUS, '76; HABERLANDT, '82). Das farblose Parenchym kann um die Gefässbündel herum oder an der Mittelrippe auftreten; letzteres ist für *Dendrocalamus latiflorus*, *Pseudosasa kurilensis*, var. *nebulosa*, u. a. zu verzeichnen.

Der Mittelnerv zeigt im Querschnitt ein grosses und 2-4 (-6) kleine Gefässbündel (Fig. 19). Sie sind von Bast umgeben und stellen meistens ein solides Gebilde dar. Die Spreite wird von zweierlei Gefässbündeln durchzogen: von den sehr grossen primären und den zwischen diesen letzteren befindlichen 2-4 (-6) kleineren, sekundären.

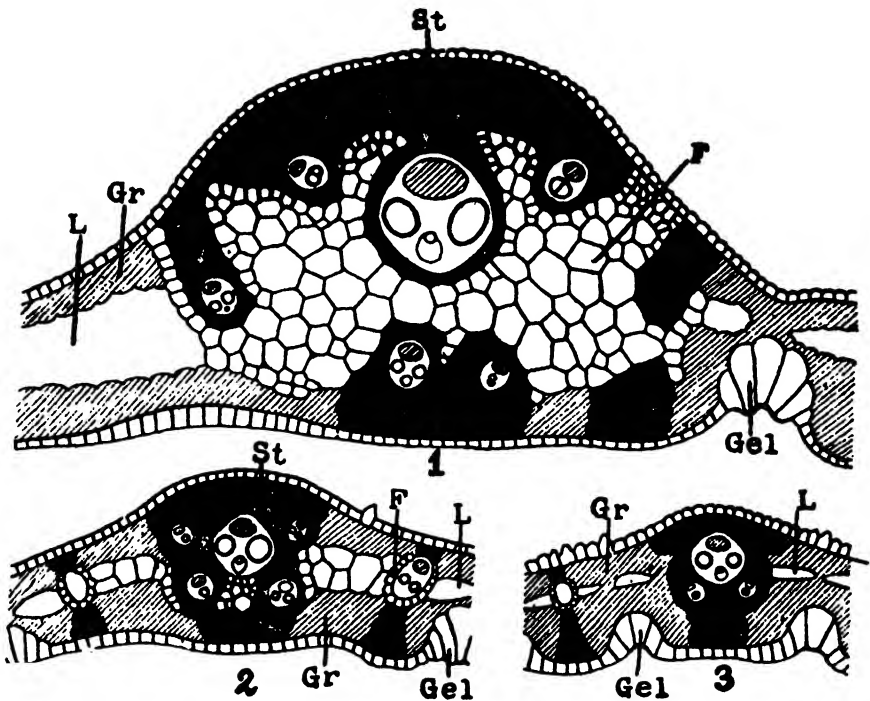


Fig. 19.

Querschnitt durch die Mittelrippe im mittleren Teil der Blattspreite:

1. *Dendrocalamus latiflorus*, 2. *Bambusa pachinensis*, 3. *Phyllostachys edulis*.

St Stereom, Gr Chlorenchym (schraffiert), F Farbloses

Parenchym, Gel Gelenkzellen, L Luftgang.  $\times 80$ .

Die Nervatur ist streifig und die Nerven sind durch schwache, rechtwinklig oder schräg ansetzende Äderchen verbunden. Die zwischen den Anastomosen eingeschlossenen Blattbezirke sind je nach den Arten verschiedenen Umrisses, sie können nämlich langgestreckt rechteckig (*Bambusa*, u. a.), ungefähr gleichseitig rechteckig (*Phyllostachys*, *Pleiblastus*, *Sasaella*, *Pseudosasa* u. a.) oder quer rechteckig (*Sasa*, u. a.) (Fig. 20) sein.

### Verkümmerte Blattspreiten.

Der anatomische Bau der verkümmerten Blattspreiten ist bisher nicht untersucht worden. Sie bestehen aus einem zwischen den beiden Epidermen eingeschlossenen lückenhaften Schwammparenchym und werden, von Gefässbündeln durchzogen, welche mit grossen Gefässen ausgestattet sind.

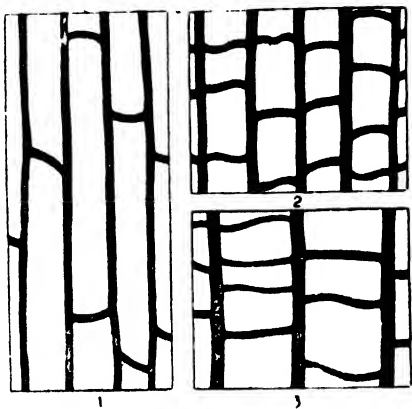


Fig. 20.

Queranastomosen der Blattnerven:

1. *Bambusa stenostachya*,
2. *Phyllostachys Makinoi*,
3. *Sasa albo-marginata*,  $\times 25$ .

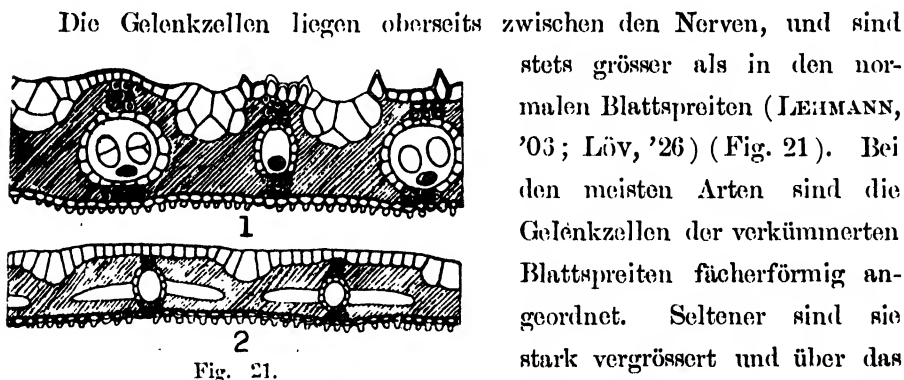


Fig. 21.

Querschnitt durch die Gelenkzellen von *Yulakeya japonica*:

1. Verkümmerte Blattspreite.
2. Normale Blattspreite.  $\times 68$ .

*albo-marginata* u. a. (Fig. 9 u. 10, Taf. II).

Die Epidermiszellen sind bei den meisten Arten, besonders auf der

sind stets grösser als in den normalen Blattspreiten (LIEHMANN, '03; Löw, '26) (Fig. 21). Bei den meisten Arten sind die Gelenkzellen der verkümmerten Blattspreiten fächerförmig angeordnet. Seltener sind sie stark vergrössert und über das Epidermisniveau vorgewölbt, wie z. B. bei *Dendrocalamus latiflorus*, *Bambusa vulgaris*, *Sasa*

Unterseite der Spreite, durch zahlreiche Kutikularwärzchen ausgezeichnet, während bei *Bambusa nana*, *Bambusa vulgaris*, *Bambusa pachinensis*, *Bambusa Olehami*, *Chimonobambusa marmorea* u. a. die Wärzchen fehlen.

Die Spaltöffnungen finden sich meist auf beiden Seiten; bei einigen Arten jedoch fehlen sie auf der Oberseite.

Bei einigen Gattungen, wie z. B. *Dendrocalamus*, *Pleioblastus* und *Sinobambusa*, weist das Mesophyll der verkümmerten Blattspreiten Membranfalten auf (Fig. 7 u. 8, Taf. II), während solche bei anderen Gattungen nicht zu sehen sind. Das Vorhandensein oder Fehlen der Armpalisaden wird in folgender Tabelle veranschaulicht. (+ Vorhandensein, — Fehlen).

TABELLE V.

Vorhandensein oder Fehlen der Armpalisaden in den verkümmerten Blattspreiten.

Gattungsnamen	Vorhandensein oder Fehlen der Falten.
<i>Dendrocalamus</i>	+
<i>Bambusa</i>	--
<i>Phyllostachys</i>	—
<i>Pleioblastus</i>	+
<i>Sasa</i>	+
<i>Sasaella</i>	+
<i>Pseudosasa</i>	+
<i>Yalakeya</i>	+
<i>Shibatata</i>	—
<i>Semiarundinaria</i>	+
<i>Sinobambusa</i>	+
<i>Chimonobambusa</i>	—



## VI. DIE KNOSPE.

### A. MORPHOLOGISCHE EIGENSCHAFTEN DER KNOSPE.

**Knospenfolge.** Die Gestalt der Knospen ist nicht nur bei verschiedenen Arten, sondern auch je nach der Halmregion, in welcher sich die Knospen entwickeln, bei einer und derselben Art verschieden. Jede Art besitzt dem Stengel entlang eine charakteristische Reihe von Knospenformen. Diese festgelegte Aufeinanderfolge bestimmter Knospenformen bezeichne ich mit dem Ausdruck „Knospenfolge“ und unterscheide a) die Knospenfolge im engeren Sinne, die sich auf die Gestalt der ganzen Knospen als solcher bezieht und b) die Vorblattfolge, welche die Beschaffenheit der Vorblätter, insbesondere ihren „Spaltungsgrad“ betrifft.

**Knospenfolge im engeren Sinne.** Die Knospenfolge im engeren Sinne wird für verschiedene Gattungen in folgender Tabelle zusammengestellt.

TABELLE VI.  
Knospenfolge verschiedener Gattungen.

Gattungsname	Stengelbasis	Basaltteil des Stengels	Mittelteil des Stengels	Spitze des Stengels
<i>Dendrocalamus</i>	nierenförmig	nahezu herzförmig	nahezu herzförmig	nahezu herzförmig
<i>Bambusa</i>	rundlich	herzförmig	herzförmig	nahezu dreieckig
<i>Phyllostachys</i>	rundlich	rhomboidal	nahezu eiförmig	nahezu dreieckig
<i>Pleiolobatus</i>	rundlich	verlängert-rhomboidal	rhomboidal od. eiförmig	lang-dreieckig
<i>Sasa</i>	rundlich od. rhomboidal	verlängert-rhomboidal	verlängert-rhomboidal	lang-dreieckig
<i>Pseudosasa</i>	rundlich	eiförmig	lang-eiförmig	lang-dreieckig

TABELLE VI. – (Fortsetzung)

Gattungsname	Stengelbasis	Basalteil des Stengels	Mittelteil des Stengels	Spitze des Stengels
<i>Shibataea</i>	rundlich od. rhomboidal	eiförmig	lang-dreieckig	lang-dreieckig
<i>Semiarundinaria</i>	rundlich	eiförmig	nahezu eiförmig	nahezu eiförmig
<i>Sinobambusa</i>	rundlich	eiförmig	eiförmig	eiförmig
<i>Chimonobambusa</i>	rundlich	nierenförmig	nierenförmig	nahezu rhomboidal

Aus der Tabelle geht hervor, dass die an der Stengelbasis sitzenden Knospen im allgemeinen rundlich, die des Basalteils des Stengels eiförmig und die weiter oben sitzenden langgestreckt sind (Ausnahmen: *Dendrocalamus*, *Bambusa*, *Chimonobambusa*).

**Vorblattfolge.** Jede der alternierend vorhandenen Knospen des Halms wird von einem Vorblatt umhüllt. Bei den meisten Monokotylen ist das Vorblatt dem Mutterspross adossiert (vgl. GOEBEL, '80 u. '05; VELENOVSKÝ, '05). Bei den Bambuseen finden wir aber das Vorblatt mehr oder minder in zwei Blätter getrennt, wonach man den geschlossenen oder gespaltenen Charakter der Vorblätter unterscheidet. Dieser ist selbst bei einer und derselben Art je nach der Lage der Vorblätter am Stengel verschieden, unsomehr bei verschiedenen Arten. Man kann hier folgende zwei Typen unterscheiden: 1. bei *Sinobambusa*, einigen *Sasa*- und *Pleioblastus*-Arten sind die Vorblätter geschlossen, sie schliessen sich nämlich zu einem Ringwall zusammen (Fig. 22 u. 23), 2. bei anderen Arten sind die beiden Ränder an der Vorderseite frei, wie dies bei *Phyllostachys*, *Chimonobambusa* u. a. der Fall ist (Fig. 22).

Der Verwachsungsgrad der Vorblätter ist je nach den Bambusarten sowie nach der Lage am Stengel verschieden. Verfolgt man die Knospen von unten nach oben, so findet man eine charakteristische Formenreihe

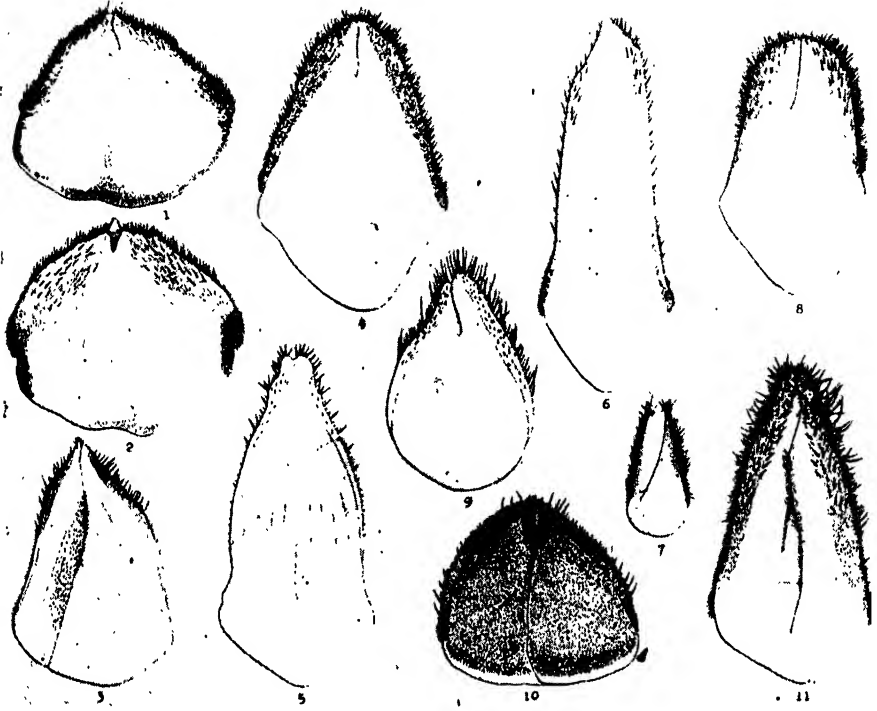


Fig. 22.

Gespaltene und geschlossene Vorblätter von verschiedenen Bambusarten:

- |  |  |
|--|--|
| 1. <i>Dendrocalamus latiflorus</i> .     | 2. <i>Bambusa stenostachya</i> .           |
| 3. <i>Phyllostachys Makinoi</i> .        | 4. <i>Pleioblastus Simoni</i> .            |
| 5. <i>Sasa albo-marginata</i> .          | 6. <i>Yadakeya japonica</i> .              |
| 7. <i>Shibataea Kunasasa</i> .           | 8. <i>Semiarundinaria fastuosa</i> .       |
| 9. <i>Sinobambusa Tootsik</i> .          | 10. <i>Chimonobambusa quadrangularis</i> . |
| 11. <i>Arundinaria niitakayamensis</i> . | × 4.                                       |



Fig. 23.

Querschnitt durch die Vorblätter:

- a Geschlossen (*Sasa albo-marginata*).  
 b Gespalten (*Phyllostachys reticulata*). × 5.

der Vorblätter, die je nach der Gattung bzw. Art verschieden ist und als taxonomisches Merkmal wohl von Nutzen sein kann. In der nächsten Tabelle stelle ich eine Reihe von

Merkmale für jede Knospenfolge zusammen (Taf. III).

TABELLE VII.  
Vorblattfolge verschiedener Gattungen.

Namen	Unterirdische, gestauchte Halmbasis	Echter Stengel
<i>Dendrocalamus latiflorus</i>	Die Vorblätter 1 u. 2 sind gespalten, alle übrigen sind geschlossen.	Die Vorblätter 1-12 sind geschlossen, von 13 ab alle gespalten.
<i>Bambusa dolichoclada.</i>	Die Vorblätter 3-5 sind gespalten, 6 ist an der Spitze mehr od. weniger gespalten.	Das Vorblatt 9 ist mehr od. weniger gespalten, oberhalb 12 sind alle gespalten.
<i>B. Oldhami.</i>	etwa wie oben.	etwa wie oben.
<i>B. pachinensis.</i>	do.	do.
<i>Phyllostachys</i> -Arten.	Alle Vorblätter sind gespalten.	Alle Vorblätter sind gespalten.
<i>Pleiolblastus Chino,</i> <i>var. argenteo-striata.</i>	do.	Ganz geschlossen.
<i>P. gramineus.</i>	do.	Die Vorblätter 1-3 sind an der Spitze mehr od. weniger gespalten. Oberhalb 4 sind alle geschlossen.
<i>P. Hindsii.</i>	Die Vorblätter 1-3 sind an der Vorderseite ganz gespalten, und 4 u. 5 mehr od. weniger gespalten.	Das erste Vorblatt ist an der Spitze mehr od. weniger gespalten; 2-9 sind geschlossen. 10 ist an der Spitze mehr od. weniger gespalten. Oberhalb 11 sind alle gespalten.
<i>P. linearis.</i>	Alle Vorblätter sind gespalten.	Die Vorblätter 1-6 sind geschlossen, 7 ist nur an der Spitze mehr od. weniger gespalten.
<i>P. Simoni.</i>	Die Vorblätter 1-4 sind gespalten, und 5 mehr od. weniger gespalten.	Die Vorblätter 1-7 sind mehr od. weniger gespalten, oberhalb 8 gespalten.
<i>P. variegata.</i>	Ganz geschlossen.	Ganz geschlossen.
<i>Arundinaria variegata,</i> <i>var. Tanakae.</i>	do.	do.

Bei *Dendrocalamus*, *Bambusa* und einigen Arten von *Pleioblastus* beträgt die Knospenzahl pro Vorblatt insgesamt 6–7 (Fig. 25 c), und zwar besitzt jede der beiden Seitenknospen erster Ordnung 2 u. 2' wiederum zwei Seitenknospen zweiter Ordnung, 3, 3' und 4, 4', an ihrem basalen Knoten (Fig. 25 a). 2) Bei einigen Arten von *Pleioblastus*, *Semiarundinaria* und *Chimonobambusa* bilden sich am basalen Knoten der Hauptknospe zwei entgegengesetzte Knospen 2 u. 2' und treiben fast gleichzeitig mit der Hauptknospe aus, so dass sich drei Knospen in demselben Vorblatt befinden (Fig. 25 b). 3) Bei *Phyllostachys* treibt die auf einer Seite der Hauptknospe sitzende Knospe zweiter Ordnung fast gleichzeitig mit der Hauptknospe aus, so dass sich zwei Knospen in demselben Vorblatt befinden (Fig. 25 c). 4) Bei *Sasa* und *Pseudosasa* zeigt sich nur die Hauptknospe, ohne gleichzeitiges Frühtreiben von Knospen zweiter Ordnung.

Die Anzahl der in demselben Vorblatt liegenden Knospen ist je nach der Stengelregion verschieden. In der nachstehenden Tabelle stelle ich diese Verhältnisse zahlenmässig zusammen.

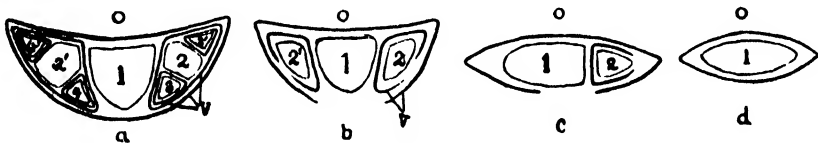


Fig. 25.

Zahl der Knospen in einem Vorblatt (Diagramm): a *Bambusa*-Arten,  
b *Pleioblastus*-Arten, c *Phyllostachys*-Arten, d *Sasa*-Arten,  
o Stengelachse, v Vorblätter.

TABELLE VIII.  
Knospenzahlen in einzelnen Vorblättern.

Namen	Basalteil des Stengels	Mittelteil des Stengels	Oberteil des Stengels
<i>Dendrocalamus latiflorus</i>	3	7	3
<i>Bambusa dolichoclada</i> .	3	7	3
<i>B. Oldhami</i> .	3	7	3
<i>B. poohinensis</i> .	3	7	3

TABELLE VIII.—(Fortsetzung)

Namen	Basalteil des Stengels	Mittelteil des Stengels	Oberteil des Stengels
<i>B. stenostachya.</i>	3	7	3
<i>Phyllostachys formosana.</i>	1	2	1
<i>P. Makinoi.</i>	1	2	1
<i>P. reticulata.</i>	1	2	1
<i>P. reticulata, var. Tanakae.</i>	1	2	1
<i>Pleioblastus Chino,</i> <i>var. argenteo-striata.</i>	1	3	1
<i>P. gramineus.</i>	1	3	1
<i>P. linearis.</i>	1	3	1
<i>P. Simoni.</i>	3	3	3
<i>P. variegatus.</i>	1	3	1
<i>Arundinaria nitakayamensis.</i>	1	3	1
<i>Sasa albo-marginata.</i>	1	1	1
<i>S. nipponica.</i>	1	1	1
<i>S. Tsuboiana.</i>	1	1	1
<i>Sasaella iwatekensis.</i>	1	1	1
<i>S. matsushimensis.</i>	1	1	1
<i>S. ramosa.</i>	1	1	1
<i>Pseudosasa spiculosa.</i>	1	1	1
<i>Yadakeya japonica.</i>	1	1	1
<i>Shibataea Kumasasa.</i>	2	3	2
<i>Semiarundinaria fastuosa.</i>	1	3	1
<i>S. viridis.</i>	1	3	1
<i>Sinobambusa Tootisk.</i>	1	3	1
<i>Chimonobambusa marmorea.</i>	3	3	3
<i>C. quadrangularis.</i>	3	3	2

Aus der Tabelle ergibt sich, dass der mittlere Teil des Stengels im allgemeinen mehr Knospen besitzt als der basale und der apikale Teil. Bei *Dendrocalamus* und *Bambusa* beträgt z. B. die Zahl der Knospen

3.....7.....u. 3....., bei *Pleioblastus*, *Semiarundinaria* und *Sinobambusa* 1....., 3.....u. 1....., bei *Phyllostachys* 1....., 2.....u. 1....., bei *Shibataea* 2....., 3.....u. 2....., während sie bei *Sasa* und *Pseudosasa* auf 1..... 1.....u. 1..... beschränkt ist.

## B. ANATOMISCHE MERKMALE DER VORBLÄTTER.

**Epidermis.** Die vergleichende Untersuchung zahlreicher Arten aus verschiedenen Gattungen ergab, dass die Epidermis der Vorblätter je nach der Bambusart verschieden beschaffen ist, wenngleich die konstruierenden Elemente im allgemeinen die gleichen sind. In der Epidermis lassen sich folgende Elemente unterscheiden: Langzellen, Kurzzellen, Spaltöffnungen und Trichome. Unter diesen Elementen machen die Langzellen den Hauptteil der Epidermis aus. Die Langzellen sind langgestreckt, haben gewellte Seitenwände und sind stets getüpfelt. Die Kurzzellen sind im Vergleich zu den Langzellen meistens kleiner und dünnwandiger, und mehr oder weniger isodiametrisch. Man kann zweierlei Kurzzellen unterscheiden, nämlich Korkzellen und Kieselzellen, welche gewöhnlich nebeneinander vorkommen, Paare oder Reihen bildend. Auf der Innenseite der Vorblätter kommen Kurzzellen sehr selten vor.

Die Epidermiszellen können als Stomata oder als Haare ausgebildet sein. Die Spaltöffnungen treten in der Epidermis der Aussenseite auf, während sie an der Innenseite entweder gar nicht oder nur in geringer Zahl aufzufinden sind. Die Weise der Anordnung der Spaltöffnungen ist je nach den Einzelfällen verschieden. Bei geöffneten Vorblättern, wie z. B. bei *Phyllostachys*, *Shibataea* u. a., sind sie reichlich an den gespaltenen freien Rändern der Aussenseite der Vorblätter vorhanden, bei geschlossenen Vorblättern dagegen, wie z. B. bei *Sasa*, *Pleioblastus* u. a. sind sie reichlicher in der Mitte zu sehen.

Haare sind bei den meisten Knospen vorhanden und lassen sich in folgende drei Typen einreihen (Fig. 26 : 1, 2, 3).

Typus I. Sehr lange ( $120-160\mu$ ), ein- od. mehrzellige, meistens bräunliche Haare. Sie kommen auf dem Rand in dessen oberem Teil<sup>1)</sup> oder auf der ganzen Fläche des Vorblattflügels vor (vgl. Fig. 27).

Typus II. Mässig lange ( $40-80\mu$ ), ein- od. mehrzellige weisse Haare. Diese kommen auf dem ganzen Rande, dem unteren Teile des Flügels und des Vorblattes vor (vgl. Fig. 27). Wenn sie sich auf dem Basalteil des Vorblattes finden, sind sie oft sichelförmig gekrümmt oder gewellt.

Typus III. Sehr kurze Haare ( $10-20\mu$ ). Zweizellige Haare sind in zwei Hauptformen vertreten: 1. an der Spitze abgerundete (Fig. 26, 3 c) und 2. etwas zugespitzte Haare (Fig. 26 3b). Sie kommen auf dem ganzen Vorblattflügel in gleichmässiger Verteilung vor.

Gleichartige Haare kommen stets in einem bestimmten Teile des Vorblattes vor und bieten je nach der Spezies besondere topographische Merkmale (vgl. JESWIET, '16) dar.

Die topographische Verteilung dieser drei Haartypen möchte ich folgenderweise mit Nummern bezeichnen (vgl. Fig. 27).

- |          |   |  |
|----------|---|--|
| Typus I. | { | 1. Am oberen Teil des Flügelrandes.      |
|          |   | 2. Auf dem Flügelrand unterhalb 1.       |
|          |   | 6. Auf dem ganzen Areal des Flügels.     |
|          |   | 10. Auf dem oberen Teile der Vorblätter. |

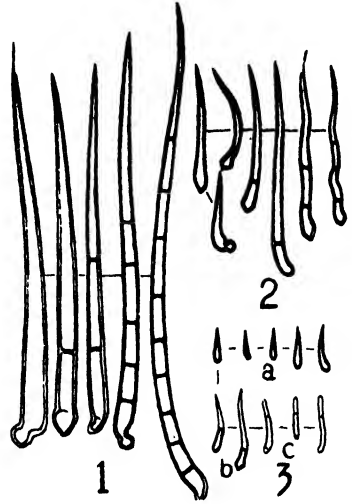


Fig. 26.

Die Haartypen auf dem Vorblatt:

1. Sehr lange, ein- od. mehrzellige Haare (Typus I).
2. Mässig lange, ein- od. mehrzellige Haare (Typus II).
3. Sehr kurze, ein- od. zweizellige Haare (Typus III).

× 103.

1) Oben, nicht weit entfernt von der Spitze, ist der Flügelrand beiderseitig oft mehr oder weniger gekrümmt und kantig. Solche Kanten sind bei *Phyllostachys*-Arten sehr deutlich. Den zwischen der Spitze und der Kante liegenden Teil bezeichne ich als oberen Randteil.



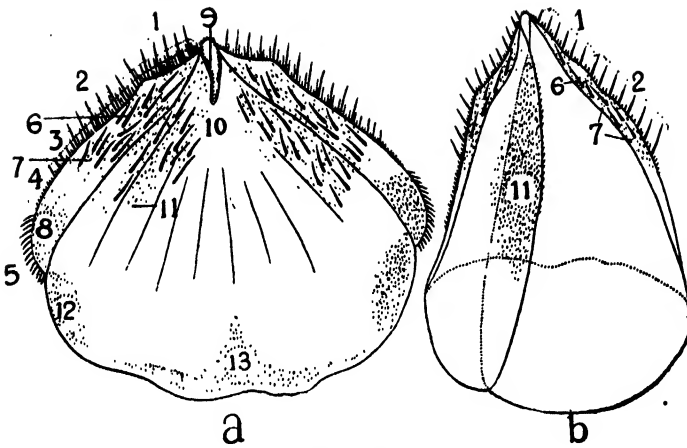


Fig. 27.

Die Haartypen auf der Aussenseite der Vorblätter (Schematisch dargestellt).

a. *Bambusa dolichoclada*.      b. *Phyllostachys Makinoi*.

1-5. Haartypen auf dem Flügelrand.

6-8. Haartypen auf dem Vorblattflügel.

9-13. Haartypen auf der Fläche des Vorblattes.

Typus II. { 3. Auf dem ganzen Flügelrande.  
5. Am unteren Teile des Randes.  
8. Auf dem unteren Teile des Flügels.  
12. Auf dem unteren Teile der Vorblätter.  
13. Auf dem Basalteile der Vorblätter.

Typus III. { 4. Auf dem ganzen Flügelrande.  
7. Auf dem ganzen Knospenflügel.  
9. Am Rande des Spitzenspaltes der Vorblätter oder  
am freien Rande der gespaltenen Vorblätter.  
11. Auf der oberen Partie der Vorblätter.

Bei einigen Arten sind diese 13 Verteilungstypen der Haare alle zu sehen, während bei anderen die Haare mehr oder minder rudimentär sind oder sogar fehlen. Diese topographische Haarverteilung lässt sich tabellarisch wie folgt darstellen :

TABELLE IX.

Die topographische Anordnung der Haare auf der Aussenseite  
des Vorblattes.

Namen	Nummernbezeichnungen der verschiedenen Anordnungsweise der Haare.												
	Flügelrand					Knospen- flügel			Fläche der Aussenseite des Vorblattes				
	1	2	3	4	5	6	7	8	9	10	11	12	13
<i>Dendrocalamus latiflorus.</i>	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Bambusa dolichoclada.</i>	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>B. Oldhami.</i>	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>B. stenostachya.</i>	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Phyllostachys formosana.</i>	+	+			+		+				+		
<i>P. Makinoi.</i>	+	+	+	+	+	+	+				+		
<i>P. reticulata.</i>	+	+	+	+	+		+				+		
<i>P. reticulata, f. Tanakae.</i>	+	+	+	+									
<i>P. reticulata, var. Martiacea.</i>	+	+	+	+		+	+		+	+			+
<i>Pleioblastus Chino, var. argenteo striata.</i>	+	+	+	+	+	+	+						
<i>P. gramineus.</i>	+	+	+	+	+	+	+						
<i>P. Hindsii.</i>	+	+	+	+	+	+	+	+					
<i>P. linearis.</i>	+	+	+	+	+	+	+						
<i>P. Simoni.</i>	+	+	+	+	+	+	+	+					
<i>P. variegatus.</i>	+	+	+	+	+	+	+						
<i>P. variegatus, var. viridis, f. pubescens.</i>	+	+	+	+	+	+	+						
<i>Arundinaria nitakayamensis.</i>	+	+	+	+	+	+	+						
<i>Sasa albo-marginata.</i>	+	+	+	+	+	+	+			+			
<i>S. Tsuboiana.</i>	+	+	+				+						
<i>Sasaella ramosa.</i>	+	+	+	+	+	+	+						
<i>Pseudosasa Kurilensis, var. nebulosa.</i>	+	+	+	+	+	+	+						
<i>P. spiculosa.</i>	+	+	+	+	+	+	+						
<i>Yadakeya japonica.</i>	+	+	+	+	+	+	+	+					
<i>Shibataea Kumasasa.</i>	+	+	+	+	+				+	+	+		

TABELLE IX. — (Fortsetzung.)

Namen	Nummernbezeichnungen der verschiedenen Anordnungsweise der Haare.												
	Flügelrand					Knospenflügel			Fläche der Aussen- seite des Vorblattes.				
	1	2	3	4	5	6	7	8	9	10	11	12	13
<i>Semiarundinaria fastuosa.</i>	+	+	+	+	+	+	+						
<i>S. viridis.</i>	+	+	+	+		+	+						
<i>Sinobambusa Tootsik.</i>	+	+	+	+	+	+	+						
<i>Chimonobambusa marmorea.</i>	+	+	+	+	+	+	+	+	+	+	+		
<i>C. quadrangularis.</i>	+	+	+	+	+	+	+	+	+	+	+		

Anmerkung: Als Vergleichsmaterial hat die fünfte oder sechste Knospe des Stengels, von unten ab gerechnet, gedient

Aus der Tabelle ergibt sich, dass am Flügelrand fast überall die oben genannten 3 Haartypen auftreten. Auf der Fläche des Vorblattes aber treten dieselben in verschiedener Weise auf. Bei *Chimonobambusa* kommen sie in reichlicher Menge vor, bei *Dendrocalamus*, *Bambusa*, *Phyllostachys* und *Shibataea* sind sie ziemlich gut entwickelt, während *Pleioblastus*, *Sasa*, *Pseudosasa*, *Semiarundinaria* und *Sinobambusa* ganz unbehaart sind.

Die Haare am Flügelrand können ein- oder mehrzellig sein. Für die Systematik ist das Vorkommen von diesen ein- oder mehrzelligen Haaren oder ihr Fehlen insofern von Bedeutung, als sie zur Bestimmung der Gattung dienen können. Bei *Dendrocalamus*, *Phyllostachys* und *Chimonobambusa* sind sie stets einzellig. Die Zahl der mehrzelligen Haare am Flügelrand ist je nach der Gattung verschieden, z. B. bei *Sasa* und *Sinobambusa* kommen sie sehr spärlich, hingegen bei *Pleioblastus* und *Pseudosasa* in reichlicher Menge vor.

Die Zahl der mehrzelligen Haare am Flügelrand des Vorblattes ist je nach der Stengelregion verschieden. Bei den an der Basis des Stengels entwickelten Knospen treten die mehrzelligen Haare gewöhnlich reichlicher auf, während sie bei denen des oberen Teils verhältnissmässig spärlich sind.

Bei einigen Arten, wie z. B. *Pleiblastus linearis*, *Arundinaria niitakayamensis* und *Sinobambusa Tootsik*, u. a. sind die Haare auf den Rändern der Vorblätter rot gefärbt. Diese Färbung ist durch im Zellsaft gelöstes Anthocyan verursacht.

**Mesophyll.** Unmittelbar unterhalb der Epidermis liegt eine dickwandige, sklerotische, subepidermale Bastplatte in Gestalt eines 1-3 schichtigen Ringes (SHIBATA, '00). Diese Bastplatte fungiert an Stelle der sog. subepidermalen Träger (SCHWENDENER, '74; Koop, '07); sie ist in den vorderen und hinteren Teilen des Vorblattes nur schwach, an den beiden Ecken aber sehr anscheinlich entwickelt.

Die Entwicklung der Nervatur im Mesophyll des Vorblattes ist je nach der Gattung sehr verschieden, so ist sie bei *Dendrocalamus*, *Bambusa*, *Phyllostachys*, *Pleiblastus* und *Semiarundinaria* stark, bei *Sasa*, *Pseudosasa* und *Arundinaria niitakayamensis* aber sehr schwach (Dies betrifft die 4. oder 5. Knospe am Stengel, von unten ab gerechnet.)

Die Bastbeläge der Gefäßbündel stossen gewöhnlich unmittelbar an die subepidermalen Bastplatten (Fig. 28). In der dickeren fleischigen Kantenpartie sind fast alle Gefäßbündel mit ihren

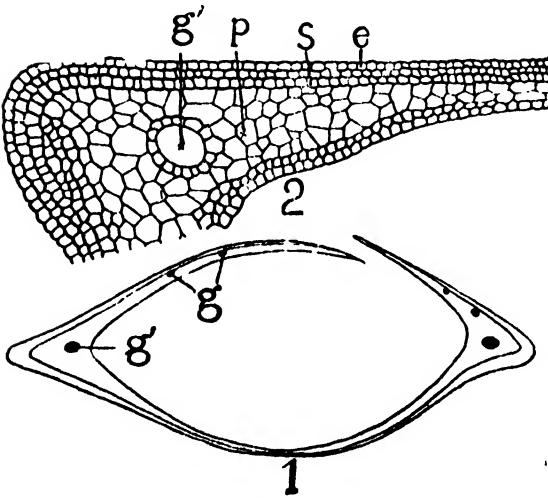


Fig. 28.

Querschnitt durch die Vorblätter von  
*Phyllostachys Makinoi*:

- e Epidermis.
- s Subepidermale Bastplatte,
- p Parenchym.
- g u. g' Gefäßbündel.

1 ( $\times 10$ ), 2 ( $\times 103$ ).

Bastbelägen ganz parenchymfrei (Fig. 28 g'). Eine vollständige Mestomscheide kann man selten bei den Vorblättern beobachten, wie das auch bei manchen Monokotylenblättern der Fall ist (HABERLANDT, '79; SCHWENDENER, '74 u. '20; Koop, '07).

## VII. BESTIMMUNGSSCHLÜSSEL.

Nach den bisher erörterten morphologisch-anatomischen Einzelheiten lassen sich die Bambus-Gattungen systematisch in folgender Weise einreihen.

### I. Unterirdische Stengel bilden einen einfachen Rasen.

- A. Haare am Knospenflügelrand einzellig . . . . . *Dendrocalamus*.
- B. do. meistens mehrzellig. . . . . *Bambusa*.

### II. Unterirdische Stengel bilden einen Rasen aus Ausläufern. . . *Arundinaria nitakayamensis*.

### III. Unterirdische Stengel mit seitlicher Rasenbildung aus Rhizomen.

#### A. Vorblätter des Halms gespalten.

- a<sub>1</sub> Haare am Knospenflügelrand einzellig. . . . . *Chimonobambusa*.
- b<sub>1</sub> do. mehrzellig. . . . . *Shibataea*.

#### B. Vorblätter des Halms nur teilweise gespalten oder ganz geschlossen.

##### a<sub>1</sub> Vorblätter teilweise gespalten.

- a<sub>2</sub> Vorblätter der unterirdischen Stengel geschlossen. Knospenzahl 1....., 1 (od. 2) .....und 1.....

##### a<sub>3</sub> Haare am Knospenflügelrand 1-2 zellig.

- a<sub>4</sub> Die zwischen den Gefäßbündelanastomosen eingeschlossenen Blattbezirke sind quer rechteckig. . . . . *Sasa*.

##### b<sub>1</sub> do. etwa gleichseitig rechteckig.

- a<sub>5</sub> Vorblattspitze symmetrisch od. doch nur leicht asymmetrisch. . . . . *Pseudosasa*.

- b<sub>5</sub> do. asymmetrisch, auf einer Seite konkav, auf der andern konvex. . . . . *Yadakeya*.

##### b<sub>3</sub> Haare am Knospenflügelrand 3-7 zellig. . . . . *Sasaella*.

- b<sub>2</sub> Vorblätter der unterirdischen Stengel gespalten. Knospenzahl 1 (od. 3) ....., 3 (od. 6-7).....und 1 (od. 3).....

##### a<sub>3</sub> Haare am Knospenflügelrand 2-6 zellig. . . . . *Pleioblastus*.

##### b<sub>3</sub> do. 1-2 zellig. . . . . *Semi-arundinaria*.

- b<sub>1</sub> Vorblätter ganz geschlossen. Haare am Knospenflügelrand durch Anthocyan geführt. . . . . *Sinobambusa*.

### IV. Unterirdische Stengel mit zerstreuter Verzweigung. Gespaltene Vorblätter . . . *Phyllostachys*.

## VIII. DISKUSSION.

Wie eingangs berichtet, hatte ich mir die Aufgabe gestellt, die japanischen Bambusarten nach ihren vegetativen Organen zu klassifizieren. Da ihre morphologisch-anatomischen Verhältnisse viele Mannigfaltigkeiten

aufweisen und, vom klassifikatorischen Standpunkt aus betrachtet, Merkmale verschiedener Wertigkeit darbieten, so dürfte sich eine systematische Einteilung der Bambusarten auf dieser Grundlage als ebenso zuverlässig erweisen wie die auf Grund der Blütenorgane durchgeführte, und ist jedenfalls weit bequemer als diese. Die morphologisch-anatomischen Eigentümlichkeiten der Vegetationsorgane der oben erwähnten 12 Gattungen lassen sich wie folgt differenzieren.

Was zunächst die Gattungen *Dendrocalamus* und *Bambusa* anbetrifft, so ist es sehr merkwürdig, dass 1) diese zwei Gattungen einen einfachen Rasen bilden, während alle übrigen Gattungen mit Rhizomen versehen sind, dass sie 2) in ihrer Wurzel eine O-Scheide besitzen (MAKINO u. SHIBATA, '01), während die übrigen Gattungen eine C-Scheide haben, und dass 3) ihre Knospenfolgen ganz identisch sind. Diese zwei Gattungen lassen sich jedoch durch die Behaarung des Knospenflügelrandes unzweideutig unterscheiden.

JESWIET ('16) hat die Zuckerrohrsorten nach den besonderen, topographischen Merkmalen der Vorblattbehaarung eingeteilt. Seine Arbeit ist wohl nur insofern als gültig anzusehen, als sie auf das in Java angebaute Zuckerrohr beschränkt wird, da, wie es mir scheint, die topographischen Behaarungsmerkmale zu gewissem Grade ökologischen Charakters sind und in der Systematik nur eine wenig wichtige Rolle spielen können. Bei Bambuseen schätze ich die diesbezüglichen Feststellungen gering ein und habe mich auf die Angabe der topographischen Behaarungstypen beschränkt, ohne ihnen weitere systematische Bedeutung beizumessen. Die Behaarung kann, meiner Ansicht nach, für die Systematik der Bambuseen einzig insofern von Bedeutung sein, als das Vorkommen resp. Fehlen einzelliger Haare am Vorblattflügelrande bei der Bestimmung der Gattungen herangezogen werden kann.

Die Art *Arundinaria nitakayamensis* (= *Indocalamus nitakayamensis*) wurde zuerst von HAYATA ('07) als eine *Arundinaria* beschrieben, dann aber von NAKAI ('25) zur Gattung *Indocalamus* gestellt. Die Art sollte aber nach meiner Ansicht als Typus einer neuen Gattung behandelt werden, da sie Ausläufer besitzt, welche, soweit aus der bisherigen Literatur ersichtlich, weder bei *Arundinaria* noch bei *Indocalamus* vorhanden sind.

Bei den 3 Gattungen *Chimonobambusa*, *Shibataea* und *Phyllostachys* sind die Vorblätter auf der Vorderseite ganz gespalten. Diese Gattungen lassen sich durch folgende Merkmale von einander unterscheiden: *Phyllostachys* hat stets zerstreute Verzweigung, während *Chimonobambusa* und *Shibataea* immer seitliche Rasenbildung aus Rhizomen aufweisen. Die beiden letzteren wiederum sind von einander durch die Ein- bzw. Mehrzelligkeit der Haare am Knospenflügelrand deutlich zu unterscheiden.

In neuester Zeit hat MAKINO ('29) seine Gattung *Sasaella* von der Gattung *Sasa* abgesondert. Ich halte dies insoweit für richtig, als die Haare am Knospenflügelrand bei *Sasaella* 3–7 zellig und die zwischen den Gefäßbündelanastomosen eingeschlossenen Blattbezirke ungefähr gleichseitig rechteckig sind. Letztere Blattbezirke scheinen für die Systematik von grossem diagnostischen Wert zu sein, weil ihre Gestalt bei einer und derselben Gattung nahezu konstant ist. Auf Grund dieser beiden Merkmale beurteilt, weist die Gattung *Sasaella* nähere Verwandtschaft mit *Pleioblastus* auf als mit *Sasa*.

MAKINO ('29) hat ferner die Gattung *Yadakeya* von der Gattung *Pseudosasa* abgesondert. Meiner Ansicht nach sollten innerhalb des früheren Genus *Pseudosasa* nach der Ausbildung der Vorblattspitze drei Gattungen unterschieden werden:

1. Vorblattspitze ausgesprochen asymmetrisch, und zwar stets auf der einen Seite konkav, auf der anderen konvex . . . . . *Yadakeya japonica* (Fig. 29, 1).
2. Vorblattspitze  $\pm$  asymmetrisch, jedoch niemals auf einer Seite, konkav . . . . .  
*Pseudosasa* (a) *spiculosa* (Fig. 29, 2).
3. Vorblattspitze symmetrisch. . . . . *Pseudosasa* (b) *Togashiana* (Fig. 29, 3), *P.* (b)  
*Kurilensis*, *P.* (b) *Kurilensis*, var. *Uchidai* u. a.

*Yadakeya japonica* und *Pseudosasa* (a) *spiculosa* stehen sich auf Grund der Asymmetrie der Vorblattspitze sehr nahe, während *Pseudosasa* (b) *sp. div.* wegen der Symmetrie nähere Verwandtschaft mit den *Sasa*-Arten aufweisen, und infolgedessen in einer neuen selbständigen Gattung untergebracht werden sollten.

Die Gattungen *Pleioblastus* und *Semiarundinaria* weisen nähere Verwandtschaft miteinander auf, und zwar auf Grund der Konstruktion ihrer Knospenfolge; sie lassen sich aber durch die Behaarung am Knospen-

flügelrand scharf voneinander absondern. Die Knospenfolge scheint hierbei berufen, für die Systematik eine grosse Rolle zu spielen, da sie, soweit mir ersichtlich, innerhalb einer und derselben Gattung ziemlich konstant ist.

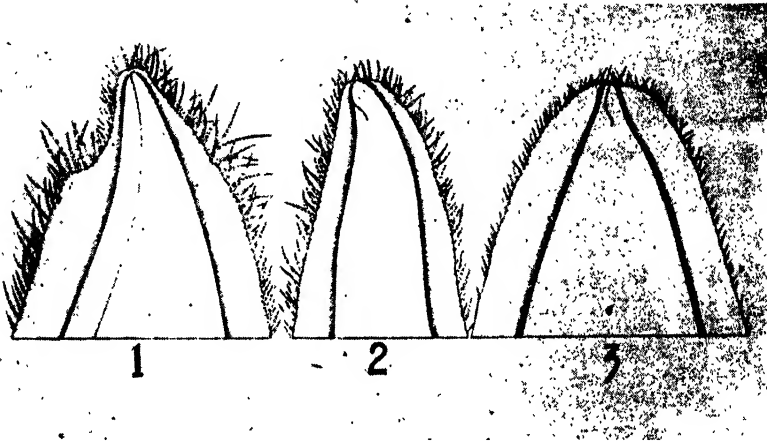





Fig. 23.








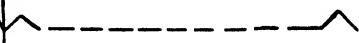
Vorblattspitze: 1. *Yadakeya japonica*. 2. *Pseudosasa* (a) *spiculosa*.  
3. *Pseudosasa* (b) *Togashiana*.  $\times 10$ .

Wenn man die verschiedenen Formen der Knospenfolge überblickt, so gewinnt man den Eindruck, dass hier bei den niedersten Bambustypen zunächst gespaltene Vorblätter aufgetreten sind (*Phyllostachys* u. a.), welche dann im Laufe der weiteren Entwicklung der Vorblattfolge in ausschliesslich geschlossene Formen übergiengen (*Sasa* u. a.).

Neben den 10 Gattungen mit bestimmter Konstruktion der Knospenfolge haben wir noch zwei Gattungen, *Pleioblastus* und *Sasa*, deren Knospenfolgen mehrere verschiedene Konstruktionen zeigen. Bei diesen zwei Gattungen weist nämlich die Vorblattfolge selbst innerhalb einer und derselben Gattung verschiedene Typen auf, nämlich geschlossene, gespaltene und teils gespaltene Vorblätter. *Pleioblastus* und *Sasa* stellen meiner Ansicht nach keine systematisch abgegrenzten Gattungen dar, sondern scheinen vielmehr ein Artengemisch aus verschiedenen Gattungen zu umfassen.



Verfolgt man die Knospenfolgen verschiedener Spezies und Varietäten bei diesen zwei Gattungen, so finden wir, dass sie nicht ganz parallel mit der taxonomischen Verwandtschaft gehen, wie in der folgenden Tabelle veranschaulicht wird. In der Tabelle stelle ich den geschlossenen oder gespaltenen Zustand des Vorblattes in Zickzacklinien dar.  bedeutet gespaltene,  zur Hälfte gespaltene,  mehr oder weniger gespaltene Vorblätter und ——— ganz geschlossene Vorblätter.

Namen	Stengelbasis	Stengel										
		1	2	3	4	5	6	7	8	9	10	11
<i>Pleiblastus Simoni.</i>												
<i>Arundinaria (Pleiblastus?) Simoni, var. variegata.</i>												
<i>Pleiblastus variegata.</i>	—	—	—	—	—	—	—	—	—	—	—	—
<i>P. variegata, var. Akebono.</i>	—	—	—	—	—	—	—	—	—	—	—	—
<i>P. variegata, var. Tanakae.</i>	—	—	—	—	—	—	—	—	—	—	—	—
<i>P. variegata, var. viridis, f. major.</i>												
<i>P. variegata, var. viridis, f. glabra.</i>												

Aus der Tabelle geht hervor, dass *Pleiblastus variegata* mit ihren Varietäten, *P. variegata, var. Akebono* und *P. variegata, var. Tanakae*, einander ähnlich sind auf Grund der geschlossenen Vorblätter, während die ihr zugerechneten Formen *P. variegata, var. viridis, f. pubescens*, und *P. variegata, var. viridis, f. major*, wegen der gespaltenen oder zur Hälfte gespaltenen Vorblätter eine nähere Verwandtschaft mit *Pleiblastus Simoni* anzeigen.

Die Vorblätter der Monokotylen sind sowohl in der vegetativen Partie wie in den Infloreszenzweigen schon von vielen Forschern wiederholt

untersucht worden (EICHLER, '75; SCHÜSTER, '10; BREMEKAMP, '15; RÜTER, '18). Es gibt über die Vorblattbildung der Monokotylen zwei Ansichten: manche Forscher (GOEBEL, '80; BREMEKAMP, '14; RÜTER, '18 u. a.) nehmen an, dass die Vorblätter durch die „Verwachsung“ von zwei Vorblättern entstanden sind, nach anderen (BUGNON, ARBER, '23 u. a.) entspräche das Vorblatt einer einzigen Blattanlage. Den Argumenten von ARBER gegenüber vertritt COLLINS ('24) in den letzten Jahren die Ansicht, dass das Vorblatt aus zwei Blattanlagen entsteht. Auf die Frage, ob für die Monokotylen ein oder zwei Vorblätter anzunehmen sind, soll in diesem geographisch beschränkten Rahmen nicht näher eingegangen werden. Meine hier gegebenen Befunde sind beschränkt auf die morphologischen Data, nämlich geschlossener oder gespaltenen Charakter der Vorblätter.

Was zuletzt *Sinobambusa* anbelangt, so zeigt sie mit *Pleioblastus* und *Semiarundinaria* ganz geschlossene Vorblätter und des weiteren starke Anthocyyanfärbung der Haare am Knospenflügelrand; es ist jedoch nicht zu vergessen, dass auch bei einigen anderen Arten Anthocyyanbildung vorkommt.

## IX. Zusammenfassung der Ergebnisse der morphologischen und anatomischen Einzeluntersuchungen.

I. In Bezug auf die Verzweigung des Rhizoms lassen sich folgende vier Typen unterscheiden:

- 1) Einfache Rasenbildung: *Dendrocalamus*, *Bambusa*.
- 2) Rasenbildung aus Ausläufern: *Arundinaria nütakayamensis*.
- 3) Seitliche Rasenbildung aus Rhizomen: *Pleioblastus*, *Sasa*, *Pseudosasa*, *Shibataea*, *Semiarundinaria*, *Sinobambusa* und *Chimonobambusa*.
- 4) Zerstreute Verzweigung: *Phyllostachys*.

II. Der Bambushalm besteht aus drei Teilen:

- 1) Unterirdische, gestauchte Zweigbasis oder Stiel.
- 2) Übergangshalm oder Stengelbasis.
- 3) Der echte Stengel oder Halm.

III. Die äussersten, kleinen Bastbündel der Internodienbasis des Halms sind in der Längsrichtung je nach der Art stärker oder schwächer nach aussen hin gekrümmt. Dieser Krümmungswinkel ist bei *Phyllostachys* ( $121^{\circ}$ – $147^{\circ}$  für die mittleren Internodien des Halms), *Sinobambusa* ( $130^{\circ}$ ), *Sasa* ( $150^{\circ}$ – $165^{\circ}$ ) u. a. kleiner als bei anderen Gattungen, wie z. B. *Pseudosasa* ( $174^{\circ}$ – $176^{\circ}$ ) u. a.

IV. Die Vorblätter sind je nach der Spezies wie nach der Halmregion geschlossen oder gespalten, und lassen folgende Typen unterscheiden:

- 1) Zum Ringwall geschlossene Vorblätter: z. B. bei *Sasa*, *Sinobambusa*.
- 2) Die Vorblätter sind alle gespalten: z. B. bei *Phyllostachys*, *Shibataea*, *Chimonobambusa* und *Arundinaria nitakayamensis*.
- 3) Die Vorblätter sind je nach der Halmregion gespalten, geschlossen, oder in verschiedenem Grade halbgespalten, so bei *Dendrocalamus*, *Bambusa*, *Pleiblastus*, *Pseudosasa* und *Semiarundinaria*, und es sollte nach meiner Ansicht ihre Einteilung von diesem Gesichtspunkt aus etwas modifiziert werden.

V. In bezug auf den geschlossenen oder gespaltenen Zustand der Vorblätter des horizontalen Rhizoms lassen sich zwei Typen unterscheiden, nämlich:

- 1) Gespaltene Vorblätter: bei *Phyllostachys*, *Semiarundinaria*, *Shibataea*, *Chimonobambusa*, *Pleiblastus* u. a.
- 2) Geschlossene Vorblätter: bei *Sinobambusa*, *Sasa*, *Pseudosasa* u. a.

VI. Die Haare auf dem Vorblattflügelrand des horizontalen Rhizoms und des Stengels sind ein- oder mehrzellig. Bei *Dendrocalamus*, *Phyllostachys* und *Chimonobambusa* kommen stets nur einzellige Haare vor, bei *Pleiblastus*, *Sasa*, *Pseudosasa*, *Shibataea*, *Semiarundinaria* und *Sinobambusa* sind sie ein- oder mehrzellig.

VII. Bei einigen Arten sind die Haare auf den Vorblatträndern durch Anthocyan gefärbt, wie z. B. bei *Pleiblastus linearis*, *Sinobambusa Tootsik*, *Arundinaria nitakayamensis* u. a.

VIII. Die Zahl der Knospen in demselben Vorblatt ist nach der Species und nach der Lage am Stengel verschieden, nämlich: bei *Den-*

*drocalamus* und *Bambusa* beträgt sie von unten nach oben am Stengel 3....., 7..... und 3....., bei *Pleiolblastus*, *Semiarundinaria*, *Sinobambusa* und *Arundinaria niitakayamensis* 1....., 3.....und 1....., bei *Phyllostachys* 1....., 2.....und 1....., bei *Shibataea* 2....., 3.....und 1....., während *Sasa* und *Pseudosasa* nur die Zahlen 1....., 1.....und 1....., aufweisen.

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## Namenverzeichnis der im Text besprochenen Bambusarten.

- Dendrocalamus latiflorus* MUNRO. (Nom. Jap. *Ma-chiku*.)
- Bambusa dolichoclada* HAYATA. (Nom. Jap. *Ch<sup>h</sup>-shi-chiku*.)
- B. dolichomerithalla* HAYATA. (Nom. Jap. *Iifuki-dake*.) :
- B. nana* ROXB. (Nom. Jap. *Howo-chiku*.)
- B. nana* ROXB. var. *normalis* MAKINO. (Nom. Jap. *Hōrai-chiku*.)
- B. nana* ROXB. var. *normalis* MAKINO, f. *Alphonso-Karri* MAKINO. (Nom. Jap. *Suli<sup>h</sup>-chiku*.)
- B. Oldhami* MUNRO. (Nom. Jap. *Ryoku-chiku*.)
- B. pachinensis* HAYATA. (Nom. Jap. *Pachina-dake*.)
- B. stenostachya* HACK. (Nom. Jap. *Shichiku*.)
- B. Shimadai* HAYATA. (Nom. Jap. *Sekikaku-chiku*.)
- B. vulgaris* SCHRADER (?). (Nom. Jap. *Kinshi-chiku*.)
- Phyllostachys edulis* RIV. (Nom. Jap. *M s<sup>h</sup>-chiku*.)
- P. edulis* RIV. var. *heterocycla* MAKINO. (Nom. Jap. *Butsumen-chiku*.)
- P. edulis* RIV., var. *heterocycla* MAKINO, f. *subconveza* MAKINO. (Nom. Jap. *Kikk<sup>h</sup>-chiku*.)
- P. formosana* HAYATA. (Nom. Jap. *Jimmen-chiku*.)
- P. Makinoi* HAYATA. (Nom. Jap. *Kei-chiku*.)
- P. nigra* MUNRO. (Nom. Jap. *Kuro-chiku*.)
- P. nigra* MUNRO, var. *Henonis* MAKINO. (Nom. Jap. *Hachiku*.)
- P. nigra* MUNRO, var. *Henonis* MAKINO, f. *Boryana* MAKINO. (Nom. Jap. *Unmon-chiku*.)
- P. reticulata* C. KOCH. (Nom. Jap. *Madake*.)
- P. reticulata* C. KOCH, f. *Tanakae* MAKINO. (Nom. Jap. *Hy<sup>h</sup>-ga-hanchiku*.)
- P. reticulata* C. KOCH, var. *aurea* MAKINO. (Nom. Jap. *Hotei-chiku*.)
- P. reticulata* C. KOCH, var. *Marliacea* MAKINO. (Nom. Jap. *Shūbo-chiku*.)
- Pleioblastus Chino* MAKINO. (Nom. Jap. *Azuma-nezasa*.)
- P. Chino* MAKINO, var. *Laydekeri* MAKINO. (Nom. Jap. *Hakone-dake*.)
- P. Chino* MAKINO, var. *argenteo-striata* MAKINO. (Nom. Jap. *Shima-medake*.)
- P. gramineus* NAKAI. (Nom. Jap. *Taimin-chiku*.)
- P. Hindsii* NAKAI. (Nom. Jap. *Kwanzan-chiku*.)



- P. Kiusianus* MAKINO. (Nom. Jap. *Fushidaka-shino*.)
- P. linearis* NAKAI. (Nom. Jap. *Ryūkyū-chiku*.)
- Arundinaria* (*Pleiblastus*?)<sup>1)</sup> *Matsunoi* MAKINO. (Nom. Jap. *Yokohama-dake*.)
- Pleiblastus Simoni* NAKAI. (Nom. Jap. *Medake*.)
- Arundinaria* (*Pleiblastus*?) *Usawai* HAYATA. (Nom. Jap. *Kawakamuri-yadake*.)
- Pleiblastus variegata* MAKINO. (Nom. Jap. *Chigo-zasa*.)
- Arundinaria* (*Pleiblastus*?) *variegata* Makino var. *Akebono* MAKINO. (Nom. Jap. *Akebono-zasa*.)
- A.* (*Pleiblastus*?) *variegata* MAKINO, var. *pygmaea* MAKINO, f. *glabra* MAKINO. (Nom. Jap. *Oroshima-chiku*.)
- A.* (*Pleiblastus*?) *variegata* MAKINO, var. *Tanakae* MAKINO. (Nom. Jap. *Sudare-yoshi*.)
- Pleiblastus variegatus* MAKINO, var. *viridis* f. b. *glaber* MAKINO. (Nom. Jap. *Nezasa*.)
- P. variegatus* MAKINO, var. *viridis* f. *humilis* MAKINO. (Nom. Jap. *Kochiku*.)
- P. variegatus* MAKINO, var. *viridis*, f. *major* MAKINO. (Nom. Jap. *Mikuni-zasa*.)
- Arundinaria niitakayamensis* HAYATA (Nom. Jap. *Niitaka-yadake*.)
- Sasa albo-marginata* MAKINO et SHIBATA. (Nom. Jap. *Kuma-zasa*.)
- S. albo-marginata* MAKINO et SHIBATA, f. *minor* MAKINO et SHIBATA. (Nom. Jap. *Ko-kumazasa*.)
- S. nipponica* MAKINO et SHIBATA. (Nom. Jap. *Miyako-zasa*.)
- S. septentrionalis* MAKINO. (Nom. Jap. *Miyama-zasa*.)
- S. Tokugawana* MAKINO. (Nom. Jap. *Tokugawa-zasa*.)
- S. Tsuboiana* MAKINO. (Nom. Jap. *Tsuboi-zasa*.)
- Sasaella iwatekensis* MAKINO et UCHIDA. (Nom. Jap. *Yabu-zasa*.)
- S. Matsushimensis* MAKINO. (Nom. Jap. *Matsushima-zasa*.)
- S. ramosa* MAKINO. (Nom. Jap. *Azuma-zasa*.)

1) Nach Nakai ('25) sollen die japanischen, bis dahin in der Gattung *Arundinaria* untergebrachten Arten sämtlich zu *Pleiblastus* gehören, und in der Tat hat Makino ('26) schon einige dieser Arten dorthin gestellt. Ich habe deshalb hier auch diejenigen *Arundinaria*-Arten; deren generische Zugehörigkeit noch nicht von autoritativer Seite festgestellt ist, als *Pleiblastus* (?) angeführt.

- Pseudosasa Kurilensis* MAKINO. (Nom. Jap. *Nemagari-dake*.)  
*P. kurilensis* MAKINO, var. *nebulosa* MAKINO. (Nom. Jap. *Shakotan-chiku*.)  
*P. kurilensis* MAKINO, var. *Uchidai* MAKINO. (Nom. Jap. *Nagaba-nemagari-dake*.)  
*P. Togashiana* MAKINO. (Nom. Jap. *Nambu-suzu*.)  
*P. spiculosa* MAKINO. (Nom. Jap. *Suzu-dake*.)  
*Yadakeya japonica* MAKINO. (Nom. Jap. *Ya-dake*.)  
*Shibataea Kumasasa* MAKINO. (Nom. Jap. *Okame-zasa*.)  
*Semiarundinaria fastuosa* MAKINO. (Nom. Jap. *Narihira-dake*.)  
*S. fastuosa* MAKINO, var. *viridis* MAKINO. (Nom. Jap. *Ao-narihira*.)  
*S. viridis* MAKINO. (Nom. Jap. *Yasha-dake*.)  
*Sinobambusa Tootsik* MAKINO. (Nom. Jap. *T-chiku*.)  
*Chimonobambusa marmorea* MAKINO. (Nom. Jap. *Kwan-chiku*.)  
*C. quadrangularis* MAKINO. (Nom. Jap. *Shikaku-dake*.)

## TAFELERKLÄRUNGEN.

## TAFEL I.

- Fig. 1. Querschnitt durch die verkümmerte Blattspreite eines Scheidenblattes des Rhizoms (*Chimonobambusa quadrangularis*); Bastbeläge der Gefäßbündel schwarz gefärbt.  $\times 103$ .  
 Fig. 2-4. Subepidermale Bastmünte aus Rhizomen; 2 *Pleioblastus variegata*, var. *viridis*, f. *b. glabra*, 3 *Pleioblastus gramineus*, 4 *Phyllostachys edulis*, var. *heterocycla*, f. *subconcreta*, a Subepidermaler Bastmantel.  $\times 200$ .  
 Fig. 5. Querschnitt durch das Niederblatt von *Phyllostachys nigra*.  $\times 103$ .  
 Fig. 6-8. Hypodermiszellen aus Niederblättern; 6 *Sasa septentrionalis*, 7 *Sinobambusa tootsik*, 8 *Pleioblastus linearis*, a Hypodermiszellen.  $\times 625$ .  
 Fig. 9. Aerenchym aus der verkümmerten Blattspreite eines Niederblattes von *Pleioblastus variegata*, var. *viridis*, f. *major*.  $\times 103$ .  
 Fig. 10, 11. Wurzelquerschnitte; 10 *Bambusa stenostachya* ( $\times 500$ ), 11 *Semiarundinaria fastuosa* ( $\times 230$ ), e Exodermis; a Sklerenchymzellen.

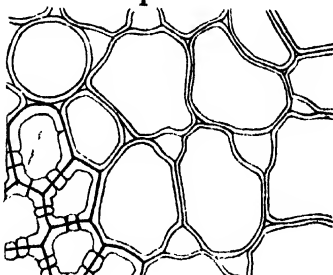
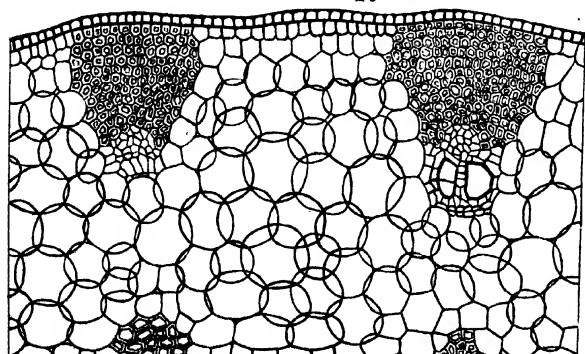
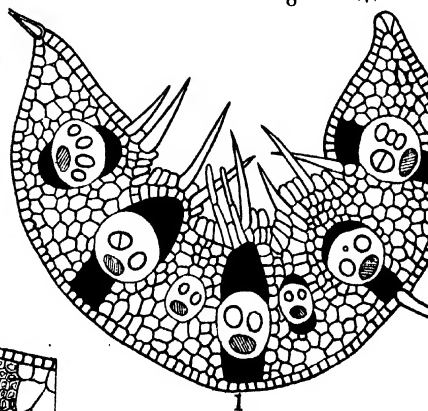
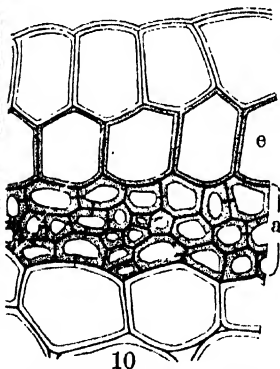
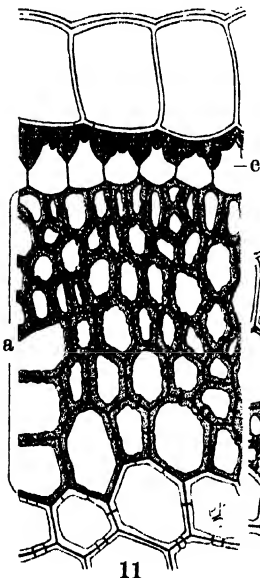
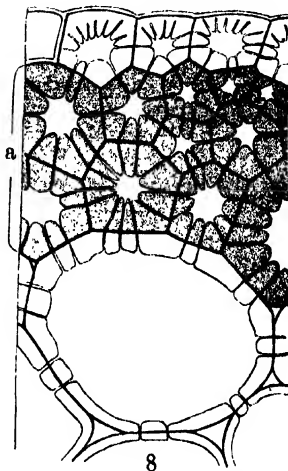
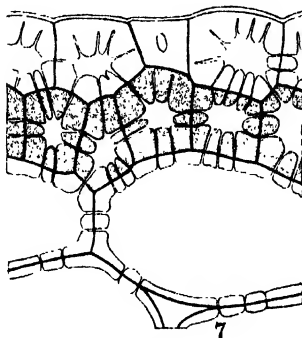
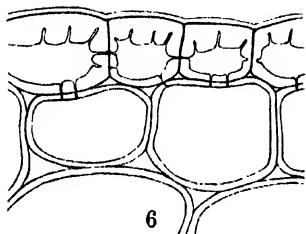
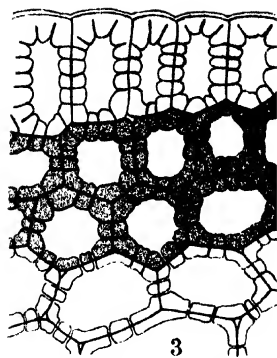
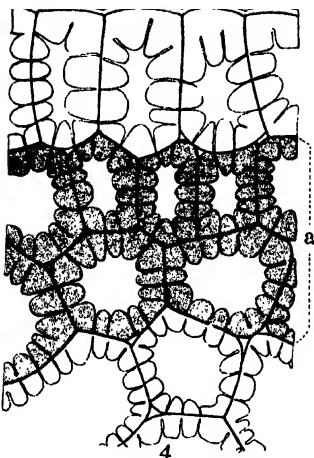
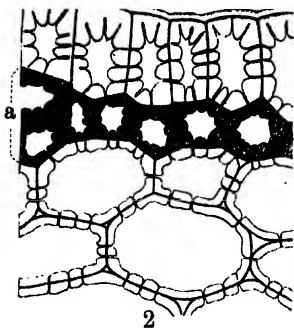
## TAFEL II.

- Fig. 1-5. Längsschnitte durch Knotendiaphragmen.  
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 Fig. 2. *Sasa septentrionalis*.  $\times 310$ .  
 Fig. 3. *Pseudosasa japonica*.  $\times 310$ .  
 Fig. 4. *Arundinaria nitakayamensis*.  $\times 103$ .  
 Fig. 5. *Dendrocalamus latiflorus*.  $\times 103$ .  
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 Fig. 7-10. Querschnitte durch verkümmerte Blattspreiten von Schösslingen; a Armpalisaden, b armloses Parenchym, l Luftgang, g Gelenkzellen.  
 Fig. 7. *Bambusa nana*, var. *normalis*.  $\times 103$ .  
 Fig. 8. *Semiarundinaria fastuosa*.  $\times 103$ .  
 Fig. 9. *Bambusa vulgaris*.  $\times 68$ .  
 Fig. 10. *Sasa albo-marginata*.  $\times 68$ .

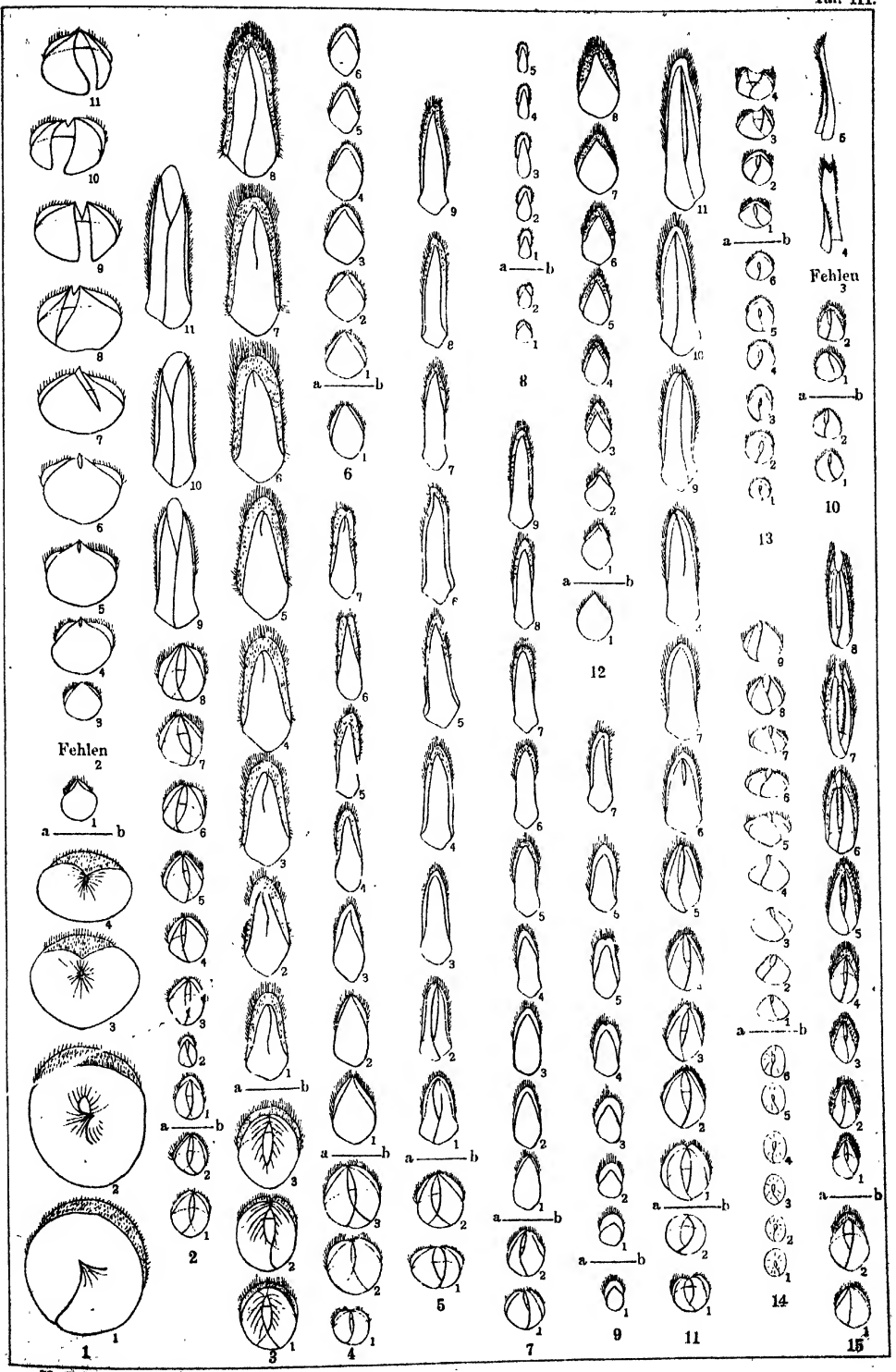
## TAFEL III.

Knospenfolgen an der Stengelbasis und am Stengel; a-b bezeichnet die Grenze zwischen der Stengelbasis und dem Stengel; die unter den Strichen liegenden Knospenfolgen gehören zur Stengelbasis, die darüber liegenden zum echten Stengel.  $\times 1$ .

- Fig. 1. *Bambusa pachinensis*.  
 Fig. 2. *Phyllostachys reticulata*.  
 Fig. 3. *Pseudosasa japonica*.  
 Fig. 4. *Pleioblastus linearis*.  
 Fig. 5. *Pleioblastus Simoni*.  
 Fig. 6. *Pleioblastus variegata*.  
 Fig. 7. *Sasa albo-marginata*.  
 Fig. 8. *Sasa albo-marginata*, f. *minor*.  
 Fig. 9. *Sasa ramosa*.  
 Fig. 10. *Shibataea Kumasasa*.  
 Fig. 11. *Semiarundinaria viridis*.  
 Fig. 12. *Sinobambusa tootsik*.  
 Fig. 13. *Chimonobambusa marmorea*.  
 Fig. 14. *Chimonobambusa quadrangularis*.  
 Fig. 15. *Arundinaria nitakayamensis*.









# Physiological Researches on Pollen, With Special Reference to the Artificial Germination of Gramineae Pollen

KAZUO GOTOH.

2 Plates and 26 figures.

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## I. INTRODUCTION.

Numerous investigations on pollen have been made since the latter part of the 18th century, to solve various problems in plant breeding or genetics, and to study its physiological characters. In these earlier investigations, however, little consideration has been paid to the physico-chemical characters of pollen, excepting by LLOYD (1917), BRINK (1924), and some others. Accordingly, precise investigations on the characteristics of pollen and its germination need to be made from this point of view, and the application of the results to practical problems is very important.

In artificial culture, which is an important means in the investigation of pollen problems, numerous methods have been attempted subsequent to the fundamental investigations of VAN TIEGHEM, (as will be seen in the following chapter in detail), but the artificial germination of pollen in many species of plants still can not be obtained satisfactorily enough for practical purposes. The pollen of Gramineae, which includes many important crop-plants, is one of the group which is difficult to bring artificially to germination. This is a great technical obstacle in the investigation of problems of plant-breeding or genetics in the plants of this family.

The present author intended to do physiological research on pollen grains in general, and, further, on those of Gramineae especially, in order to get some methods of artificial culture which will be available for the practical purposes of pollen germination in the plant group last mentioned.

It is a pleasure to acknowledge the invaluable criticism and encouragement given to the writer during this investigation by Prof. T. SAKAMURA, under whose supervision the work has been done. To Drs. K. MIYABE, S. ITO, I. NAMIKAWA, K. KONDO, and H. KIHARA the writer wishes to express his sincere thanks for the helpful advice, continuous encouragement, and much courtesy in allowing him the use of their libraries. The writer is also indebted to Mr. G. MIYANO, Mr. B. ISHIDA, and his colleagues for their kind help.

## II. Historical Review of the Artificial Germination of the Pollen Grain.

It can be easily understood that different special methods might be desired for the culture of pollen of different plants, because they are different in their morphological structure, size, chemical composition, etc. We need to examine all the methods used up to date, before the beginning of these experiments, especially in an attempt to overcome the difficulty of artificial culture of the pollen of certain plants, such as Gramineae.

The fact that the pollen grain of some species can germinate in water is found in VON MOHL's book (1834). SCHLEIDEN (1849) stated in his book that almost every kind of pollen might germinate in the nectary of Crown Imperial, *Hoya carmosa*, etc., or sometimes merely in a dilute solution of honey. Since those earlier discoveries, numerous attempts have been made on the germination of pollen grains of several kinds of plants with or without positive results.

We can roughly classify the media used into 5 kinds.

1. Pure water.
2. Sugar solution.
3. Agar-agar or gelatine medium containing sugar.
4. Solid or liquid media with some chemicals, enzyme, or a piece of plant tissue as a stimulant or supplementary substance.
5. Mechanical regulation of the water supply.

DE MOHL (1834) first described the germination of pollen grains of some plants in pure water. VAN TIEGHEM (1869), LIDFORSS (1896, 1899), and HANSGIRG (1897) found that a great many kinds of pollen could germinate easily in pure water. This characteristic is very common in several plants.

The first report of the application of a sugar solution for pollen germination may be found in SCHLEIDEN's book (1849). Since ELFYING (1879) proposed that sucrose is more suitable for the germination of pollen than other kinds of sugar, almost all experiments of this kind have been done with a sucrose solution. ELFYING (1879) and MOLISCH (1893) determined the optimum concentration of sugar solution for the germination of many kinds of pollen, and found that most of them could germinate in sugar solutions of a pretty wide range of concentration. MOLISCH (1893), however, could not bring the pollen of certain plants to germination either in a 1-50% sugar solution (with or without gelatine), in a glycerin, in a gum solution, or even in pure water. Such plants belong to the Compositae, Umbelliferae, Urticaceae, Malvaceae, and Ericaceae. LIDFORSS (1899) used various kinds of sugar, with or without the addition of various acids, for the germination of Gramineae pollen, but his results were not satisfactory. BURCK (1900) reported the favorable effect of levulose on *Mussaenda* pollen, and LIDFORSS (1909) recognized the power of a lactose solution to promote the germination of pollen of *Cerastium hirsutum*. MARTIN (1913) found different effects on the germination of pollen of the *Trifolium* species.

KNY (1881), in his research on the influence of outer factors on the growing pollen-tube and the fungus mycelium, chose gelatine medium for the pollen germination in the same way as that first used by BREFELD

(1874) for fungus culture. Agar-agar was preferred by MANGIN (1886) in order to avoid the sinking of pollen grains into the culture medium and their accumulation in a mass. After the application of those solid media, RITTINGHAUS (1887), using a 1.5% gelatine, and PFUNDT (1909), and Sasaki (1919), both using a 1% agar-agar,<sup>1)</sup> determined the optimum concentration of sugar solutions for the germination of a great many kinds of pollen.

LIDFORSS (1909) found a difference in the pollen germination and in the subsequent growth of the pollen-tube in the cases of gelatine medium and agar medium. He succeeded by using a 30-40% sucrose-agar medium in the culture experiments on the pollen grains of certain plants,<sup>2)</sup> which had been known as those which do not germinate on any other medium than their own stigma. However, JOST (1905) previously cast some light on this problem of the artificial germination of difficult material by the use of parchment paper soaked with a sugar solution. LIDFORSS (1909) found that in many cases<sup>3)</sup> the pollen-tube germinated on the agar medium has a stronger vitality than that on the gelatine medium. On the contrary, gelatine stimulates the germination of pollen and the subsequent growth of the pollen-tube in some special cases. For instance, the pollen of *Lysimachia punctata* generally germinates on a sucrose-gelatine medium (20% sucrose, 2% gelatine) but rarely on a sucrose-agar (20% sucrose, 1% agar) medium.

The pollen of *Rhododendron indica*, *R. arboreum*, and *Azalea indica*, which had not been found to germinate in any artificial media mentioned above, but only on its own stigma, was easily brought to germination by MOLISCH (1893) with a very dilute solution<sup>4)</sup> of malic acid or calcium malate. LIDFORSS (1896) reported good results from using a very weak solution of citric acid in the cases of *Erica ciliaris* and *E.*

1) SASAKI used 5% agar-agar medium for the pollen of *Hordeum sativum*, *Oryza sativa*, etc.

2) *Herianthus speciosus*, *Myrrhis odorata*, *Meum athamanticum*, *Althaea officinalis*.

3) *Liliaceae*, *Bromeliaceae*, *Rutaceae*, *Tropaeolaceae*, *Rosaceae*, *Papaveraceae*, *Hydrophyllaceae*, *Scrophulariaceae*, *Gesneriaceae*, etc.

4) Good germination was obtained in a 0.01% solution.

*pedunculata*. SANDSTEN (1909) found that tomato pollen requires a slightly acid medium for its germination, and TISCHLER (1910) stated that the "Beköstigungspollen" term given by MÜLLER (1883), can be induced to germinate by adding saliva or diastase to the culture.

The addition of the living stigma or style, or its decoction, to the culture medium has been known to promote the germination and the further growth of the pollen-tube. Above all the most interesting fact in this direction is KNOWLTON's observation that pollen grains of *Antirrhinum majus*, which were stored in air of 10–20°C. for 670 days, failed to germinate in a plain sugar solution, but by the addition of a piece of stigma, a germination of 50 percent was secured. Of those which were kept in pure oxygen, 10 percent germinated.

Certain kinds of pollen were known to need a delicate regulation of the water supply for their germination. Almost all species of Gramineae and *Trifolium pratense* belong in this class. For the germination of these kinds, of pollen special attempts were made, such as to regulate the water supply in a mechanical way. JOST (1905) occasionally found that only the pollen grains which stood outside of the culture drop on a cover glass and were kept merely in a moist condition came to germination. He tried to use the lower surface of leaves of *Lymnanthemum nymphacoides* and *Hydrocharis*<sup>5)</sup> in the living condition with good results for *Dactylis* pollen germination. Again, even both sides of the boiled leaf of *Lymnanthemum* and the lower surface of the boiled leaf of *Menianthes* could serve satisfactorily for the germination of *Dactylis* pollen. *Dactylis* pollen germinated very well on parchment paper which was properly dried in the air after soaking with pure water, or which received suitable moisture by being floated on pure water. The same material soaked with a sugar solution<sup>6)</sup> gave a rather good germination of Compositae pollen.

Parchment paper and hog bladder were used by MARTIN (1913) for his study on pollen germination in *Trifolium pratense*. The former

5) SASAKI (1919) tried leaves of the same kinds of water plants without any positive result.

6) JOST said that no remarkable difference could be found among sucrose, maltose, dextrose, and levulose.

did not bring any good results. MARTIN found that good germination was obtained on the latter membrane, which was soaked with a sucrose or a levulose solution and then properly dried. The membrane soaked with distilled water gave as good results as that with a sugar solution. He could not, however, obtain uniformly good results, either in every set of experiments, or in different parts of one trial.

ANTHONY and HARLAN (1920) secured the germination of barley pollen both with mesophyll tissue from green leaves and with a free drop of water as the source of moisture. The important difference of that technique from other methods was that the chamber of germination was loosely closed and that after the preparation the slide glass was placed on the outside ledge of the window.

ITAKURA (1922) covered one end of VAN TIEGHEM's cell with hog bladder and fixed it with the other end on a slide glass, filling it with a sucrose solution. He got a somewhat good germination in the case of the pollen of some cereals.

After reviewing these artificial culture media and techniques in detail, it may be said that the most suitable methods for the general purpose of pollen germination are hanging drop cultures with sugar solutions with or without agar or gelatine, and that no sort of artificial medium as nearly satisfactory as stigma is made for the germination of pollen, which requires a remarkably delicate regulation of the water supply.

In the present paper two methods were used for general investigation. The one (culture method I) was the so-called "hanging drop culture". The glass rings employed were perfectly ground at each end and measured 18.0 mm. in diameter and 12.0 mm. in height. A glass ring was mounted on a slide glass, and fixed with paraffin. The top of the ring was then coated with a thin layer of vaseline, and the cover glass bearing the culture drop was so inverted over the cells as to make a hanging drop. A drop of culture solution was transferred to the cover glass by means of a clean glass rod drawn to a small point. A few drops of the same solution as that to be ~~used~~ for the culture were

placed on the bottom of the cell, in order to establish a complete equilibrium of vapor pressure in the cell and to prevent changes in the concentration of the culture drop. The transfer of the pollen to the culture drop was accomplished with the point of a needle.

The other media used were prepared of sugar-agar or sugar-gelatine. These media were melted in a water bath and poured into a petri dish measuring 36 mm. in diameter and 18 mm. in depth. It was uncovered until the medium become cool, in order to prevent condensation of superfluous water vapor on the surface of the medium (culture method II).

All of the pollen grains in the culture drop were counted at the start of the culture, and the percentages of germination and bursting were calculated at definite intervals. In the case of solid medium cultures, pollen counts were made in five different microscopical fields of one culture, and the average percentage of germination was recorded.

The determination of the pH value of every culture solution and medium was made either electrometrically or by means of CLARK and LUBS' indicators.

Only glasses which had been tested to be practically alkali-free hard glass were used for this work. The method of this test is as follows: Take some most carefully double-distilled water (pH 6.9-7.1 by driving off  $\text{CO}_2$ ) in a previously tested hard glass beaker and add some drops of phenol red. Glasses to be tested are put in water thus prepared and left for a few minutes in it. We can easily find out by the color change whether any alkaline substance is dissolved out or not. Boiling is better for finding out such a difference in quality of glass.

### **III. The Influence of the Quality of the Glass on Pollen Germination.**

It is a well known fact that alkali easily dissolves out of ordinary glass, and even before an accurate method for the determination of the hydrogen-ion concentration was devised, alkalinity in a certain degree

was considered to play an important rôle in several physiological phenomena. From the foregoing chapter we can recognize that in all methods for pollen germination, except a few of those in class 5, media were used which came in touch with glassware once at least. Nevertheless, no attention had been paid to the quality of the cover glasses, slide glasses, or dishes, etc. which were used in the artificial cultures of pollen grain until my preliminary paper (1924) on this subject was published. Accepting the writer's advice in that paper, YASUDA (1927a, b, and 1928) and YASUDA and ARAI (1927) used Leitz's hard cover glass for their germination experiments of the pollen of *Petunia violacea*.

Because this methodical precaution as to glassware is very important in the investigation on pollen germination and as the previous paper was published in the Japanese language, it will be again described here in detail.

The pollen which germinated readily in pure water is suitable material for experiments with dilute solutions, because the regulation of the osmotic value of the culture solutions can be neglected. LINDQVIST (1896) investigated widely the susceptibility of several plant pollens to water. In order to find out such pollen as just mentioned, the following experiment was made.

## EXPERIMENT I.

In this experiment a drop of double-distilled water,<sup>7)</sup> which was large enough not to dry out in a few hours, was placed on a slide glass, and then the pollen grains of various plants were suspended in it directly from anthers. The slide glass was placed on a table in the laboratory and covered with a petri dish. After a few hours the germination and, at the same time, the bursting of the pollen grains were observed under the microscope. The results are shown in Table I.

7) The double distilled water was very carefully prepared by the distillator designed by Prof. SAKAMURA. Its pH value, driving out CO<sub>2</sub> gas, was determined as 6.7-7.2 by means of the indicator phenol red and brom thymol blue.



TABLE I.

<i>Amaryllis</i> sp.	—
<i>Antirrhinum majus</i> L.	—
<i>Begonia</i> sp.	+
<i>Bassica campestris</i> L.	—
<i>Cannabis sativa</i> L.	+
<i>Chacnomeles cardinalis</i> Nakai.	++ +
<i>Clivia nobilis</i> Lindl.	+
<i>Catalpa bignonioides</i> Walt.	+++
<i>Corylus rostrata</i> , Ait. var. <i>Sieboldiana</i> Maxim.	++
<i>Digitalis purpurea</i> L.	+
<i>Hamamelis japonica</i> Sieb et Zucc.	—
<i>Impatiens Balsamina</i> L.	++++
<i>Iris tectorum</i> Maxim.	×
<i>Linum usitatissimum</i> L.	×
<i>Lupinus perennis</i> L.	++++
<i>Lysichiton camtschatense</i> Schott.	++++
<i>Pelargonium zonalle</i> Willd.	×
<i>Paeonia albiflora</i> Blume.	+++
<i>Rhododendron dahuricum</i> L.	++ +
<i>Rumex Acetosella</i> L.	++
<i>Salix rorida</i> Lackschewitz.	+
<i>Spinacia oleracea</i> L.	—
<i>Tea japonica</i> L. var. <i>spontanea</i> Makino.	++ +
<i>Tradescantia virginica</i> L.	++
<i>Trillium kamtschaticum</i> Pall.	—
<i>Tropaeolum majus</i> L.	—

+ Corresponds to 25% germination.

— No germination.

× Bursting.

Germination experiments with the pollen of *Lysichiton*, *Paeonia*, etc. in solutions of sucrose, glucose, and dilute solutions of various salts were made, of which the first one showed good results. The other

results were very irregular, especially with the pollen of *Lupinus* and *Impatiens* only a small percentage of germination was obtained. What difference of the condition of the culture can be considered to be the cause of such different results?

The probable causes of the condition may be :

1. A hanging drop or a culture drop resting on the slide glass.
2. The culture in the open air or enclosed in a moist chamber.
3. The quality of the cover glass and slide glass.

In order to determine which of these conditions may play the main rôle, the next experiment was carried out.

## EXPERIMENT II.

The rate of germination of pollen grains of *Impatiens Balsamina* cultured in double-distilled water on different kinds of glass was observed in this experiment. Results are shown in Table II.

TABLE II.

Method \ Kind of glass	Slide glass (green tint)	Slide glass (colorless)	Cover glass (Leitz's)	Cover glass (T)*
The water drop was placed on glass. (open)	###	—	###	—
Hanging-drop culture (closed)	###	—	###	—
Hanging-drop culture (open)	###	—	###	—

\* Trade mark.

According to these results, it is very clear that conditions 1 and 2 have little to do with germination and that the third one is the important one in this relation. That is to say, the difference of the quality of glass can bring about a very striking difference in the results.

In order to test the quality of the glasses, equal amounts of double-distilled water were taken in 4 non-alkaline glass beakers, and drops of the indicator (phenol red solution) were added to it until the water was colored slightly. Double-distilled water showed a light yellow tint, when phenol red was added, because its pH value was about 5.3, which was caused by a small amount of dissolved carbonic acid. After separately dipping the 4 kinds of glasses, above mentioned in Table II, in the colored water, the change of color was observed. In the case of the colorless slide glass and the cover glass ( $\mp$ ), the color of a thin layer of the water on the surface of the glasses soon changed to light pink even when the water was not boiled. On the other hand, in the cases of the remaining two kinds of glasses no change of color could be observed even after a long while. Though they were boiled in water for a time sufficient to drive away  $\text{CO}_2$  gas, the color of the indicator remained the same as that of the control water in which no glass was immersed. This showed clearly that at least no alkaline substance was dissolved out of these two kinds of glasses. When an alkaline cover glass was floated on the water containing the indicator, the diffusion of the dissolving alkaline substance from the lower surface of the glass towards the bottom of the beaker could be observed, because the pink color shows its traces. According to these observations, when an alkaline cover glass is used the accumulation of an amount of alkaline substance, which is enough to cause a pretty high actual alkalinity, may be expected in a short time.

Therefore the different results of the above experiment (Table II) were due to the influence of alkaline substance dissolved out of the glass.

### EXPERIMENT III.

Comparative experiments on the influence of the quality of the cover glasses have been made with two kinds of glass.

In case A, non-alkaline cover glasses were used which were prepared from thin slide glasses tested as non-alkaline by the above described

method. In case B, ordinary commercial cover glasses with the trade mark  $\mp$ , which had been tested as alkaline, were used. For the material, pollen grains of *Lysichiton camtschatense* were used. They were cultured in glucose solutions of various concentrations by means of hanging-drop cultures. Results are shown in Tables III (cultured at 22°–23°C.) and IV (cultured at 17°–22°C.).

TABLE III. (See Fig. 1)

Conc. of Glucose		1.00	0.75	0.50	0.25	0.10	0.05	0.01	0.005	0.0005	0.00005	0.00
pH value of sol.		4.94	5.11	5.11	5.13	5.30	5.13	5.11	5.49	5.37	5.37	5.37
Percentage of germination	A	0	0	0	61	73	66	69	73	74	73	64
	B	0	5	22	*)	60	5	73	67	63	50	57

\*) Observation was impossible, the hanging-drop being broken.

Fig. 1. (Table III)

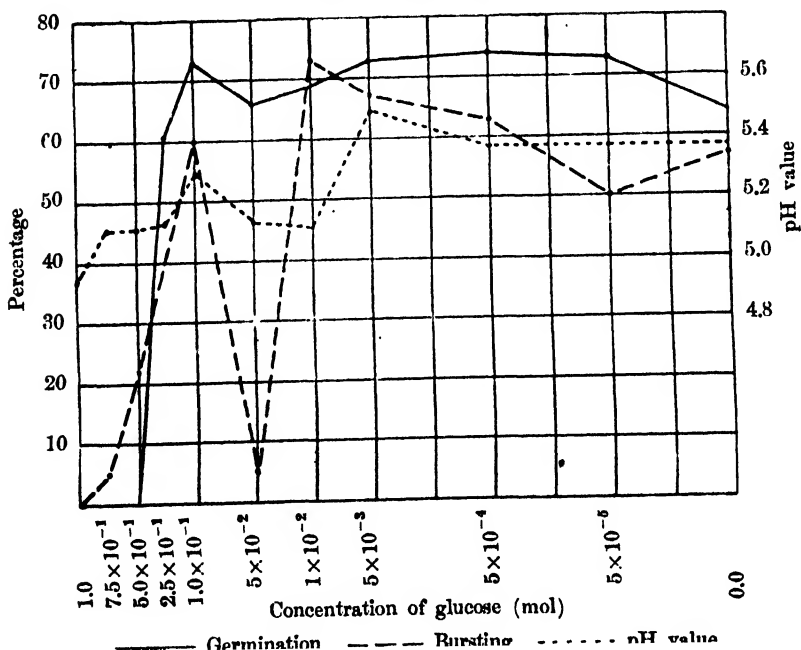


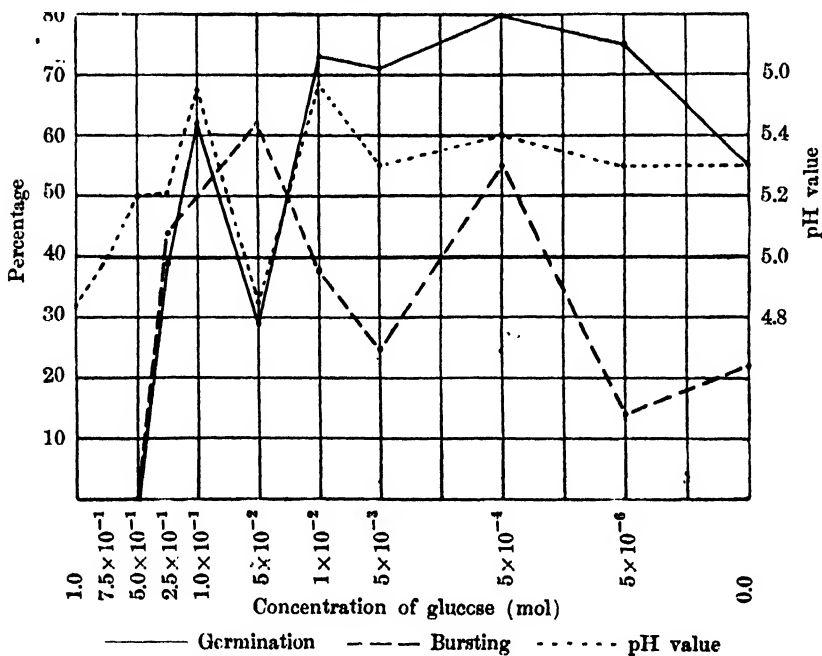
TABLE IV. (See Fig. 2)

Conc. of glucose		1.00	0.75	0.50	0.25	0.10	0.05	0.01	0.005	0.0005	0.00005	0.00
pH value of sol.		4.85	5.00	5.20	5.21	5.55	4.85	5.57	5.30	5.40	5.30	5.30
Percentage of germination	A	0	0	0	39	62	29	73	71	80	75	55
	B	0	0	0	44	*)	62	38	25	55	14	22

\*) Observation was impossible, the hanging-drop being broken.

It has been found that the variation of the pH value of glucose solutions of various concentrations, which is shown in Tables III and IV, was due to alkaline substances dissolved out of a pipette, when solutions were under preparation, because the author used a common glass pipette<sup>8)</sup> at that time. The factors which caused the remarkably low pH

Fig. 2. (Table IV)



- 8) That alkaline substance is dissolved out of such a pipette (10 cc.) can be easily demonstrated by using the pH indicator methyl-red. The first five cc. of the solution shows a smaller pH value than the last five cc.

value of the 0.05 mol solution are not clearly known, but such higher acidity might be caused by a trace of impurity in the sugar and the frequency employment of a pipette during the dilution of the solutions. Anyhow, these tables show that besides the influence of the concentration of sugar, i.e., the osmotic pressure, the pH value of the solution has an intimate relation to the germination of pollen grains. In case B, when soft cover glass was used, results were irregular, independent of the concentration of the glucose solution and of its initial pH value, while in case A pretty regular results were obtained. In Table III a better germination of pollen grain can be seen in the higher concentrations of the glucose solution in case B than in case A. In the culture of the 0.75 and the 0.50 mol solutions, in case B the pollen grains germinated, while no germination occurred in these concentrations in case A. That these irregularities in results may not be due to the osmotic relation, but mainly to the alkaline substance dissolved out of the cover glass, is to be seen in the concentration of 0.01 mol in Table III and of 0.25 and 0.05 mol in Table IV. When the pH value was relatively small, the percentage of germination in case B often surpassed that in case A. By the dissolved alkaline substance the initial pH values of the sugar solutions in these cultures were probably altered to that corresponding to the hydrogen-ion concentrations more suitable for the germination of pollen. It is a difficult matter to determine such changes of the hydrogen-ion concentration in the drop culture. Therefore, attention must always be paid to the quality of glassware when using sugar solutions or single salts solutions which have a very weak buffer action.

#### IV. The Morphological Character of Pollen grains.

A few points concerning the structure of pollen grains which relate to germination have been observed.

The wall of a pollen grain is constructed out of two layers, the external cutinized layer and the internal layer. The former is broken at the germ-pore. MANGIN (1889) called them exine and intine res-

pectively, and found that the outer side of the latter layer consists of cellulose associated with some pectic substance, "callose", although STRASBURGER (1882) did not succeed in distinguishing the intine. BOURGE (1892), confirming MANGIN's results, found that the germination begins with an evagination of the intine. The present author has also made micro-chemical researches with the pollen grain, and found that "intine" consists of pectic substance.

The inner structure of the pollen grain has, as far as the writer is aware, not yet been studied. For the purpose of this study, young pollen grain is more suitable than ripe grain, because the latter has well defined pollen membranes and abundant reserve materials, making the observation of the inner structure very difficult. Therefore, in the present investigation the former was used. 'Pollen grains were taken on a dry slide glass directly from anthers at the instant of their dehiscence, and their appearance of turgidity was quickly observed.' Results are shown in Table V.

TABLE V.

Name of plant	Total volume of vacuoles in pollen grain	Appearance of turgidity of pollen grains at the time of the dehiscence of anthers
<i>Avena sativa</i>	++ <sup>1)</sup>	— <sup>2)</sup>
<i>Cannabis sativa</i>	++	—
<i>Digitalis purpurea</i>	++	+ <sup>2)</sup>
<i>Impatiens Balsamina</i>	+ <sup>1)</sup>	+
<i>Oenothera Lamarckiana</i>	++	+
<i>Oryza sativa</i>	++	—
<i>Secale cereale</i>	++	—
<i>Tradescantia virginica</i>	++	++ <sup>2)</sup>

- 1) ++ volume of vacuoles in pollen grain is larger than a half of pollen grain.  
 + volume of vacuoles in pollen grain is smaller than a half of pollen grain.  
 2) ++ pollen grain shrinks remarkably.  
 + pollen grain shrinks to some degree.  
 — no shrinkage.

TABLE V. — (Continued)

Name of plant	Total volume of vacuoles in pollen grain	Appearance of turgidity of pollen grains at the time of the dehiscence of anthers.
<i>Trifolium pratense</i>	+	+
<i>Triticum vulgare</i>	++	—
<i>Tropaeolum majus</i>	+	+
<i>Zea Mays</i>	++	—

Every pollen grain observed in the experiment has vacuoles in its young stage. The appearance of turgidity of the pollen grain at the time of the dehiscence of the anthers is very different according to the kind of plant. Gramineae pollen has no shrinkage and that of *Tradescantia virginica* shows very remarkable shrinkage which decreases the volume of the pollen grain to  $\frac{1}{3}$  its volume in the state of turgescence.

## V. The Artificial Germination of the Pollen Grain and the Growth of the Pollen-tube, with special Reference to their Bursting.

### 1. Relation to Osmotic pressure and Hydrogen-ion concentration.

Since the discovery of the artificial germination of pollen grain was made, many investigators have attempted to cultivate the pollen of various plants artificially. They have faced a source of no little annoyance, especially in the case of Gramineae pollen. That is the bursting of the pollen grain and the pollen tube. In the case of many kinds of pollen, the perplexity of the bursting has been overcome by the regulation of the concentrations of the sugar solutions. MOLISCH (1893), PFUNDT (1910), SASAKI (1919), and others have described how pollen of a great many species germinates readily in sugar solutions varying widely in concentration. For instance, pollen grains of *Lilium martagon* and *Epipactis latifolia* germinate in solutions containing 1 to 50 percent sugar (MOLISCH, 1893) and those of *Camellia japonica* and *Hyacinthus*



*orientalis* in sucrose solutions ranging from 0 to 1.6 mol (TOKUGAWA, 1914).

VAN TIEGHEM (1869) found that the pollen of *Ricinus communis*, which does not burst in pure water, bursts in a thick solution of gum arabic. He concluded, "Ce fait montre que l'explication ordinaire de la ruputre, basée sur l'irruption violente du liquide externe due à sa densité relative, ne s'applique pas à tous les cas". Analogous observations which were made in *Primula acaulis* by CORRENS (1889) convinced him that the bursting of the pollen-tube is independent of the concentration of the culture solution. LIDFORSS (1896) observed similar facts in many plants. For instance, the pollen of *Aesculus Pavia* germinates very well in distilled water, but almost all bursts in a 30 percent sucrose solution. He considered from these facts that the change in growth or the elasticity of the intine has some certain rôle not to be overlooked. These evidences make the phenomena difficult to explain by the osmotic relation.

LLOYD (1911) worked on the behavior of tannin in persimmons, and alleged that the bursting of certain kinds of cells (tannin-idio-plast, raphide-cells, etc.) placed in solutions of crystalloids, glycerol, etc. of higher concentrations than those of the cells themselves, could not be due to the osmotic pressure, but to the imbibition of water by cellular emulsoids. And again he explained in his work (1917) that the total outwardly direct pressure playing against the cell wall must be the combined effect of osmotic pressure and that of imbibition, and that when the musilages are highly dispersed, the pressure will be correspondingly low, osmotic pressure may be the dominant factor. A like conclusion has been reached by KNOWLTON (1922) from his germination experiments with corn and snapdragon pollen. The fact that when a definite concentration of sugar is necessary, any departure from it results in failure to germinate or in abnormal germination, made him conclude that ["as the water content of corn pollen is high, it is probable that osmotic pressure plays an important part, both in the swelling of the grain and in its subsequent growth."] On the other hand, in the case

of *Antirrhinum* pollen the water content is low and the pollen germinates in almost any concentration of sugar. Therefore Knowlton says that "Imbibition is probably more important here than is osmosis".

In the writer's experiments, pollen of *Lysichiton camtschatense* germinates well in glucose solutions ranging from 0 to 0.25 mol (Tables III and IV). In these tables we can find unexpected differences of the pH values of the sugar solutions. The germination curves show a certain fall at the concentration of 0.05 mol remarkably paralleled with the pH curves. A similar falling has been reported by KNOWLTON (1922) in the germination of *Antirrhinum* and apple pollen with sucrose solutions (see his Tables 2 and 5), though he did not pay any attention to the point mentioned above. The present writer cannot say surely that the cause of the phenomenon observed by Knowlton is the same as that of his own. However, it is probable that even in the pure sugar solution the germination of pollen is influenced by some other powerful factors besides the concentration. As one of them we can consider the hydrogen-ion concentration of the culture solution. Here we must take separately into account each factor which influences the pollen germination. It is, however, absolutely impossible to study these related factors all together at the same time in one solution. Therefore it is necessary to investigate at first one limited factor by keeping the others constant.

The hydrogen-ion concentration was recognized at first by the biochemist as one of the most important factors in ferment investigation and biocolloidal chemistry. For investigation in plant physiology, too, there is no doubt that this factor plays a very important rôle. In the investigation on the physiology of pollen, however, only a little attention has been paid in this direction. Only one article, as far as the author is aware, has been published. It is by BRINK on the germination of the pollen of *Lathyrus odoratus* (1925).

## EXPERIMENT IV.

In the following experiment, the relation between the bursting as well as the germination of the pollen of *Lysichiton* and the hydrogen-ion concentration of the culture solution was studied. It was done by hanging-drop cultures at room temperature, 11.5°-17°C. For the culture solutions SPRENGER's phosphate buffer mixture (M/50) was used. Results are shown in Table VI.

TABLE VI. (See Fig. 3)

pH value of sol.	5.35	5.60	5.90	6.25	6.47	6.64	6.85	7.25	7.45
Number of pollen grains	146	123	219	84	147	172	120	187	204
	101	56	114	77	110	94	118	74	55
	120	75	63	52	113	104	100	55	65
Mean	122	84	132	71	123	123	112	105	108
Percentage of bursting	93.2	95.1	96.3	95.3	88.8	90.4	84.1	85.0	8.3
	95.0	91.1	83.6	84.4	43.6	39.4	14.4	39.2	0
	80.8	88.0	93.6	80.8	45.1	79.8	26.0	13.0	12.3
Mean	89.7	91.4	91.2	86.8	59.2	69.9	41.5	45.7	6.9
Percentage of germination	2.8	3.4	2.2	3.8	6.3	7.8	7.5	0.5	41.8
	0	0	7.7	6.5	34.5	50.0	54.2	5.4	18.2
	3.3	0	0	5.8	48.7	11.5	22.0	1.8	6.2
Mean	2.0	1.1	3.3	5.4	29.8	23.1	27.9	3.6	22.1

From Table VI we can find that very many pollen grains burst in the solutions from pH 7.25 to 5.35. Between pH 6.47 and 6.85 the percentage of bursting shows a slight decrease, and a remarkable decrease at pH 7.45. The germination curve, showing a clear contrast

to the bursting curve, at pH 6.47, 6.85, and 7.45 has a larger magnitude.

Although the pollen of *Lysichiton camtschatense* easily germinates in distilled water (see Tables III and IV), much bursting occurred in the buffer solution of M/50. Of course, this must be due mainly to the influence of the hydrogen-ion concentration.

In order that the turgescence of the pollen grain or the pollen-tube in a solution may be sustained in an equilibrium, the resistance power of the membrane (wall pressure) ( $P_w$ ), especially at the germ-pore, and the turgor pressure of the pollen grain must be numerically equal. The turgor pressure is created by the total outward pressure of the pollen grain due to the difference of the osmotic value of the osmotically active contents in it ( $P_a$ ) and that of the outer solution ( $P_b$ ) and the imbibition (i.e., swelling) power of the colloidal contents, including protoplasm ( $P_c$ ). This relation in the equilibrium can be expressed by the following formula :

$$P_w = (P_a - P_b) + P_c \dots\dots\dots(1)$$

The resistance of the membrane against the inner pressure, especially of the intine at the germ-pore, is limited within a certain degree. When the pollen grain is immersed in a strong hypotonic solution, the turgor pressure overcomes the resistance of the intine and the plasma membrane at the germ-pore and the bursting of the pollen grain takes place.  $P_a$  and  $P_b$  can be taken as equal (isotonic) by the regulation of  $P_b$ , the concentration of the culture solution. Then

$$P_w = P_c \dots\dots\dots(2)$$

In this condition, i.e., in the isotonic solution, the relation between the resistance of the membrane and the imbibition power of the colloidal substances, mainly protoplasm, may play the main rôle in bursting. Therefore the disturbance of the equilibrium between the turgor and the resistance power of the membrane, including the exine, the intine, and the plasma membranes, is caused mainly either by the remarkable change of the turgor pressure of osmotic nature or by the change of the colloidal

characters of the plasma colloid and of the membranes at the germ-pore. As mentioned in the chapter on the morphological character of pollen grains, they have a small content of plasma, but pretty large vacuoles, and the degree of the shrinkage on the wall of pollen grains varies with the kind of plant. Therefore  $P_o$  in such a case, may be almost negligible in the equation (1). In the case of  $(P_a - P_b)$  being constant, the variation of the rate of the bursting of pollen grains depends mainly on the change of the nature of the protoplasm and the membrane at the germ-pore, which may be caused by several factors. As one of them, the hydrogen-ion concentration must not be overlooked.

### EXPERIMENT V.

In this experiment the influence of the hydrogen-ion concentration on the germination and the bursting of pollen grains, by regulating the concentration of added glucose, was studied. Material and buffer solutions are the same as in Experiment IV. The experiment was done at room temperature.

A. Material: Pollen grains of *Lysichiton camtschatense*.

Culture solution: M/50 SØRENSEN'S phosphate mixture + 3/10  
mol glucose.

Results are shown in Table VII.

B. Material: The same as in A.

Culture solution: M/50 SØRENSEN'S phosphate mixture + 3.5/10  
mol glucose.

Results are shown in Table VIII.

C. Material: The same as in A.

Culture solution: M/50 SØRENSEN'S phosphate mixture + 4/10  
mol glucose.

Results are shown in Table IX.

TABLE VII. (See Fig. 3)

pH value of sol.		4.7	5.0	5.3	5.9	6.5	7.0
Number of pollen grains	A	201	188	171	162	120	178
	B	99	202	80	103	111	140
	Mean	150	195	125	132	115	159
Percentage of bursting	A	78.6	68.6	88.9	59.3	5.8	0
	B	81.8	70.8	95.0	68.0	14.4	1.4
	Mean	80.2	69.7	92.0	63.7	10.1	0.7
Percentage of germination	A	8.5	9.0	5.3	24.1	77.5	83.7
	B	10.1	23.8	2.5	29.1	75.7	93.6
	Mean	9.3	16.9	3.9	26.6	76.6	88.7

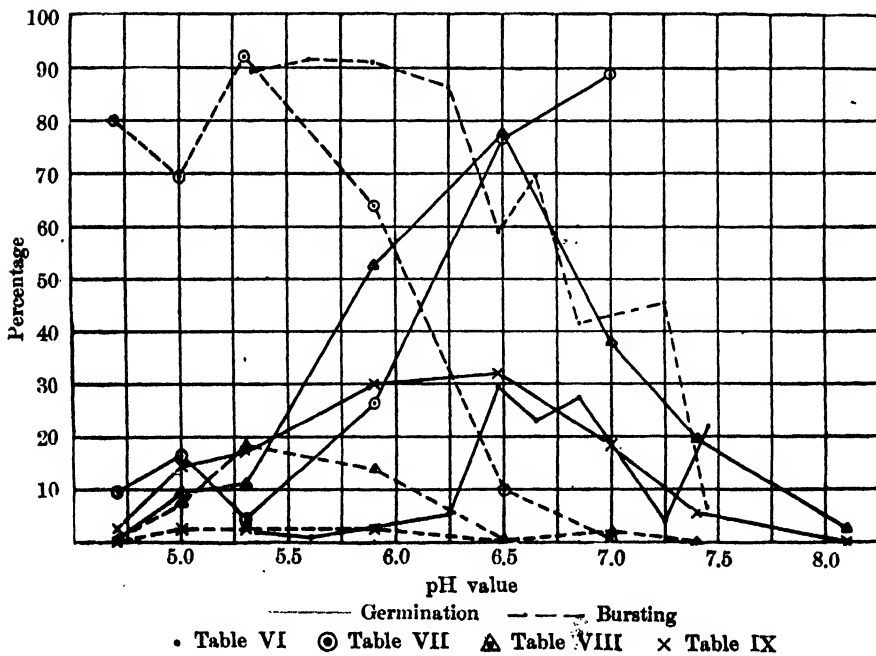
TABLE VIII. (See Fig. 3)

pH value of sol.		4.7	5.0	5.3	5.9	6.5	7.0	7.4	8.1
Number of pollen grains	A	187	122	192	124	162	151	136	154
	B	217	111	116	95	180	128	126	145
	Mean	202	116	154	109	171	139	131	149
Percentage of bursting	A	0	13.9	24.0	13.7	0	4.0	0	0
	B	0	0.9	12.9	14.7	0.6	0	0	0
	Mean	0	7.4	18.5	14.2	0.3	2.0	0	0
Percentage of germination	A	0.5	13.9	17.2	58.1	74.7	57.6	33.8	5.8
	B	0	5.4	4.3	46.3	80.6	18.8	5.6	0
	Mean	0.3	9.7	10.8	52.2	77.7	38.2	19.7	2.9

TABLE IX. (See Fig. 3)

pH value of sol.		4.7	5.0	5.3	5.9	6.5	7.0	7.4	8.1
Number of pollen grains	A	144	201	172	121	105	117	119	127
	B	123	103	118	134	109	132	93	165
	Mean	133	152	145	127	107	124	106	146
Percentage of bursting	A	0	3.5	4.7	5.8	0	0	0	0
	B	0	1.9	0	0	0	0	0	0
	Mean	0	2.7	2.4	2.9	0	0	0	0
Percentage of germination	A	0.7	23.4	29.7	33.1	47.6	20.9	6.7	0
	B	4.9	5.8	5.9	26.9	16.5	6.8	4.3	0
	Mean	2.8	14.6	7.8	30.0	32.1	18.4	5.5	0

Fig. 3. (Tables VI-IV)



## EXPERIMENT VI.

The time relation of the germination and the bursting of pollen grains is observed in this experiment. The culture solution and the material are just the same as those of Experiment V-B. The cultures were done at 9–10°C. Results are seen in Table X.

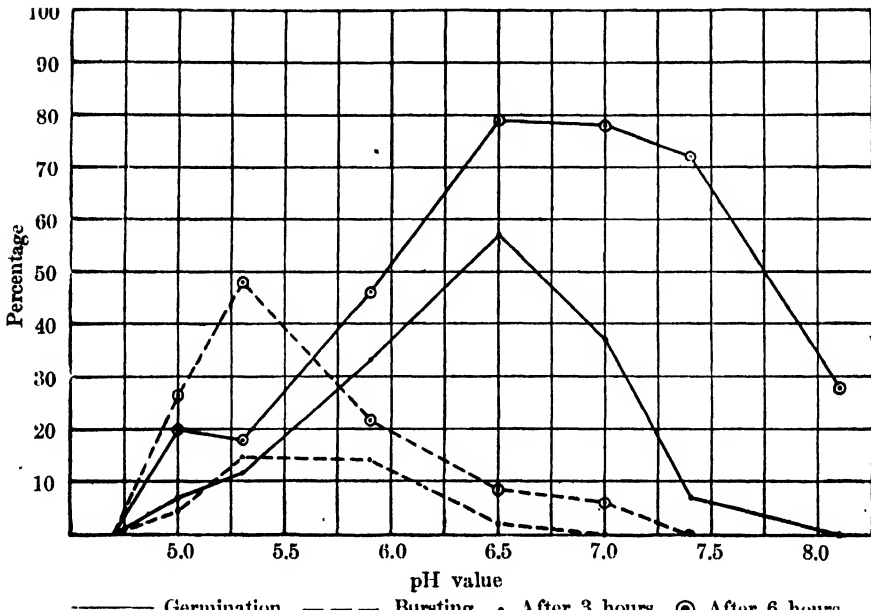
TABLE X. (See Fig. 4)

pH value of sol.		4.7	5.0	5.3	5.9	6.5	7.9	7.4	8.1
Number of pollen grains		73	92	80	70	55	76	62	38
Time of culture (in hours)	3	Percentage of bursting	0	4.5	15.0	14.0	1.9	0	0
		Percentage of germination	0	7.1	11.6	32.8	57.2	36.7	7.0
	6	Percentage of bursting	0	26.5	47.7	21.4	8.4	6.1	0
		Percentage of germination	0	20.9	17.9	46.1	78.7	78.5	72.1

In these tables it is noted that when the osmotic value of the culture solution increases, the percentage of the bursting of the pollen decreases and that of the germination of the pollen grains increases, whilst beyond a certain concentration of the culture solution they decrease. The maximum bursting takes place in the cultures of pH 5.0–5.9. The optimum pH for the germination varies from 7.0 to 6.5. These two zones coincide with the zone which show the largest amount of bursting and that which shows a fall in the bursting curve and maximum germination in Table VI. Table VII shows that when a slight amount of bursting occurs, the optimum zone of germination of *Lysichiton* pollen can be seen at pH 5.9–6.5. From these facts it might be possible to suggest that even in the case of pollen which has neither a well defined nor a pretty narrow range of optimum concentrations of sugar for germination, the bursting of the pollen can be remarkably controlled by the increase of sugar in the culture solution. Even in the above men-



Fig. 4. (Table X)



tioned case, the osmotic pressure must be one of the main factors in the in the bursting of the pollen. That the pollen, which germinates in a well defined optimum concentration of the medium, bursts due to osmosis is a well known fact. Therefore, osmosis must be considered one of the main factors in the germination and the bursting of every kind of pollen. On the other hand, we must consider the elasticity of several kinds of membranes, especially intine. Many kinds of pollen are able to germinate in a wide range of concentrations of sugar solution. This fact shows that the mechanism of pollen germination depends not only on osmosis, but on the character of the protoplasm and the membranes. If the elasticity of the membranes of the pollen and the consistency of the cytoplasm are included in our consideration, it is very clear that the wall pressure ( $P_w$ ) is enough to fill up the difference of  $P_a - P_b$  (equation 1) within the limit of resistance of the membranes.

Therefore the width of the range of the concentration of the sugar solution suitable for the germination of pollen depends on the nature of the membranes and plasma colloid. That is to say, the pollen which

has very delicate membranes shows a clear cut osmotic relation and needs a delicate regulation of the water supply, while that which has the stronger membranes will not easily burst and germinate in a wider range of concentrations of sugar solution. Of course, a moderate firmness of the membranes and a suitable balance between the inner pressure and the wall resistance in the pollen are necessary conditions for its germination. The consistence of the membranes, especially the intine and the plasma membrane, will be changeable in various pH values or in the presence of other kinds of ions, and is independent of the osmotic pressure of the culture solution. The weaker the resistance of the membranes, the more bursting occurs. Therefore the pH value of the maximum bursting is constant (Table VII-IX).

That the acidity and the alkalinity of the solution have great influence on such characters as the swelling or the viscosity of the colloidal substances or the rate absorption of water, etc. is a well known fact.

LLOYD (1917) studied the colloidal properties of protoplasm in the pollen-tubes of *Lathyrus odoratus*. By increasing the quantity of various acids in a 20 percent sucrose solution he did not succeed in accelerating the rate of growth of the pollen-tubes. But only when acetic acid was used, combined with 40 percent sucrose—this concentration of sugar used as the control—an increase of the rate of growth took place in the acid of concentrations of N/25600 up to N/1600, the maximum growth being in N/3200. Bursting occurred also in N/1600. A clearly analogous effect of alkalis was found in a 20% sugar solution. The rate of growth increased at the concentrations N/800 to N/12800. Comparing these results with the experiments with gelatine, LLOYD concluded that the living protoplasm, as such, behaves towards acids and alkalis in a manner sufficiently like that of gelatine to warrant the view that imbibition is a factor in growth.

ROBBINS (1923) worked on the iso-electric point with potato tuber, and found that the absorption of water is influenced by the hydrogen-ion concentration of the surrounding solution, as is the case of other

colloidal substances. COHN, GROSS, and JOHNSON (1920), and PEARSALL and EWING (1924) have determined the iso-electric point of the protein of press-juice of various plants. As iso-electric points they determined the pH values which are situated between 4.0 and 5.0.

SAKAMURA and LEO (1925) found a two- or more- maximum curve in their experiments on the displacement of the chromatophores of *Spirogyra* by treatment with centrifugal force. In these experiments they centrifuged the material treated in buffer solutions and determined the softness of the protoplasm. In acidic zones about pH 4.9-5.3, 6.4, and 7.5-7.6 hardening of protoplasm occurred, and chromatophores could be removed only with difficulty. Between these zones the protoplasm was more soft and the displacement took place easily. Only one similar investigation with pollen grains was made by KIHARA (1923). He made comparative investigations on the protoplasm of the pollen of the *Triticum* species by means of pollen bursting in hypotonic solutions of various pH, and obtained a three-maximum curve. STRUGGER (1926, 1928) reported also such a polymaximum curve in barley root hair. It is a well known fact that the hydrogen-ion concentration effects the swelling and the viscosity of various colloidal substances.

BRINK (1924) could not agree with the view held by VAN TIEGHEM (1896), CORRENS (1889), MOLISCH (1893), and LIDFORSS (1896), that the amount of bursting is unrelated to the osmotic force of the surrounding medium. That pollen grain can germinate in sugar solutions of widely different concentrations was proved by MOLISCH (1893), TOKUGAWA (1914), ADAMS (1916), EAST and PARK (1918), and others. BRINK concluded that "the evidence suggests the conclusion that the cell membranes of the pollen grain and its tube are or become permeable to cane sugar, and that the final result as far as osmotic pressure is concerned is the same as though the surrounding medium were water", in spite of his conclusion that "the bursting of tubes so frequently encountered in the artificial culture of pollen is interpreted as an osmotic phenomenon". MANGIN (1886), DODEL (1878), and TISCHLER (1917) observed the accumulation of starch in pollen-tubes growing in sugar

solutions. This may be the cardinal evidence that induced BRINK to advance his "diffusion theory".

LIDFORSS (1896) cultured the pollen of *Loberia cardinalis* in three, two, and one percent sucrose solutions. On transferring them into distilled water after one hour's time in the solutions, a large number in the first lot burst, a relatively large number of the second, and none of the third. He made analogous experiments with the pollen of other *Loberia* sp., *Nicotiana macrophylla* and *Glaucium luteum*, and got quite the same results. BRINK (1924) gave his "simplest explanation" to the facts that "if the pollen is somewhat permeable to cane sugar, so that during the hour in the culture media, the original osmotic pressure of the solution within the tubes becomes increased by an amount approaching that of the surrounding solution, the tubes, when transferred to distilled water, will tend to burst the more freely the higher the concentration of the solution in which they were grown".

The author made an analogous experiment with the pollen of *Hyacinthus orientalis*.

## EXPERIMENT VII.

Pollen grains of *Hyacinthus orientalis* were cultured on a medium consisting of 1 percent agar and one mol sucrose. After two hours' cultivation in an incubator at 20°C a small drop of each sugar solution of the different concentrations was dropped on a culture. With culture "c" (Table XI) first a drop of a 0.975 mol sugar solution was used. After a 4 minute interval the solution was removed with a piece of blotting paper, and then it was replaced by a 0.950 mol solution. Similar treatments of the same culture were repeated until a 0.900 mol solution was dropped upon it; decreasing the concentration by 0.025 mol each time. The last replacement directly jumped to 0.700 from 0.900 mol. In the culture "f", the replacement of the sugar solution was made gradually as in the early part of culture "e", with the same interval of decrease of 0.025 mol each, to a 0.700 mol solution. Table XI represents the results.

TABLE XI.

Percentage of bursting of pollen-tubes							
Culture	Concentration of sugar solution in mol						
	0.957	0.950	0.925	0.90	0.85	0.75	0.70
a	20						
b		28					
c				100			
d					100		
e	20	—*	—	—			50
f	20	—	—	—	—	—	—

\* (—) represents no increase of bursting of pollen-tubes.

From these results we can recognize that as the difference of the concentration of sugar solutions from that of the original culture medium becomes greater, the more bursting of the pollen-tubes occurs, as was expected. Although all of the pollen-tubes burst in a 0.90 mol solution (culture "c", the cultured pollen can be transferred even in a 0.700 mol solution without any augmentation of the bursting of the pollen-tubes, if a careful, gradual decrease of the concentration is practiced (culture "f". The total change of osmotic values for 28 minutes in the culture "f" is equal to that of a 0.3 mol sugar solution. According to BRINK's "diffusion theory", osmotic active substances in the pollen-tube, mainly sugar, should diffuse out in order to balance with the osmotic pressure of the outer solution. From this assumption such an amount of sugar as would cause the osmotic pressure in the pollen grain and the pollen-tube to decrease from that of 0.975 mol to that of 0.7 mol of sugar, should diffuse out into the outer solution within 24 minutes. That such a considerable amount of sugar can diffuse out through the plasma-membrane in such a short time, does not seem to be probable under normal conditions. The diffusion of sugar out of the agar medium into the drops would disturb the accurate

change of the sugar concentration in such a method. The diffusion of sugar in an agar medium is, however, so slow, that the amount of sugar diffused into a drop will be very small, and the drop will keep nearly the same concentration of sugar for a short while. Therefore, if the concentration of the sugar solution is of a sufficient dilution to cause the bursting of the pollen tube, that concentration will be kept unchanged at least until the bursting takes place. If this be true, the influence of the diffusion of sugar out from agar medium may be practically neglected.

After all, when the concentration of the culture solution decreases very gradually, the membrane of the tip of the pollen-tube and the neighbourhood can regulate its state to match the lowering of the concentration of the outer solution. On the other hand, if an extensive lowering of the concentration takes place at one time, it does not give enough time for the regulation of the physical condition of the pollen membrane, and bursting will occur. When the concentration of the culture solution is decreased step by step, the increase of the outward pressure in the pollen is not very great in each change. The pollen-tube can grow rather quickly. Therefore, the osmotic relation between the outside and the inside of the pollen grain and the pollen-tube can be balanced by the lowering of the concentration of its cell sap due to the volumetric change of the pollen grain and the pollen-tube. In the cultures "e" and "f", these changes of the osmotic relation would occur at every step of the replacement and it should be possible to remove the pollen-tubes to a culture solution of pretty low concentration without an increase of bursting. On the other hand, in the case of "c" and "d" in which the concentration of the culture solution is decreased extensively at a time, not only the increase of the outward pressure is very large, but also the regulation of the physical condition of the membrane of the pollen-tube is not quick enough to keep its resistance against the inner pressure, and the bursting of the pollen-tubes increases.

✓ **2. Effects of some Inorganic Salts on the Bursting  
of the Pollen Grain.**

The influence of the hydrogen-ion concentration of the culture media on the germination of pollen has been discussed in the foregoing chapter. It was found that the nature of the buffer solutions has a bearing, as well as the hydrogen-ion concentration, on the pollen germination and the growth of the pollen-tubes. Therefore, other ions which are contained in the buffer solution should be considered together with the hydrogen-ion.

MOLISCH (1893) observed the stimulating effect of malic acid and Ca-malate on the germination of the pollen of *Azalea indica* and *Rhododendron ponticum*, which would otherwise germinate only on the stigma.

LIDFORSS (1896) found that  $\text{KNO}_3$ ,  $\text{NaCl}$ , and  $\text{CaCl}_2$  are toxic in 0.1–0.01% solutions. The effects of these salts, however, were not uniform on different species. For instance,  $\text{Ca}(\text{NO}_3)_2$  was very toxic to *Nicotiana* pollen but relatively harmless to *Lobelia* pollen, while just the reverse results were secured with  $\text{KNO}_3$ . In his further investigation, LIDFORSS (1899) found the toxicity of egg albumin could be avoided by dialysation. This was attributed to salts which were inherent in egg albumin.

JOST (1907) made cultures of *Hippeastrum* pollen with harmless results in 0.01–0.001% solutions of  $\text{KNO}_3$ ,  $\text{K}_2\text{HPO}_4$ ,  $\text{CaSO}_4$ , or  $\text{FeSO}_4$ , but  $\text{ZnSO}_4$  showed toxic action in solutions of the same concentrations.

TOKUGAWA (1914) worked with 0.001 solutions  $\text{KCl}$ ,  $\text{KNO}_3$ ,  $\text{NaCl}$ ,  $\text{NaNO}_3$ ,  $\text{CaCl}_2$ ,  $\text{MgCl}_2$ ,  $\text{MgSO}_4$ ,  $\text{P}_2(\text{NO}_3)_2$ ,  $\text{FeSO}_4$  and with the balanced solution accompanied by sucrose (5%). He observed toxic effects in most cases. Pollen of *Primula* sp. in  $\text{CaCl}_2$  and *Hyacinthus* pollen in  $\text{NaCl}$  and  $\text{CaCl}_2$  grew better than in the control cultures.

PATON (1912) reported that the pollen of several species showed better growth on a modified KNOP's agar medium than in the other media used.

Recently, more careful experiments were made by BRINK (1924 a and b). He used alkali and alkali-earth metal salts for sweet-pea pollen

cultures and ascertained that chlorides of the bivalent cations, Mg and Ba, are roughly fifteen times as toxic as the corresponding salts of such monovalent cations as Na, K, and Li. In the case of *Nicotiana* pollen, salts of alkali and alkali-earth metal and others have been tested. With the exception of Mg and Zn, all salts tested were injurious in various degrees. The effects of  $\text{CaCl}_2$  and  $\text{MgCl}_2$  upon *Nicotiana* pollen were quite different from those on sweet-pea pollen. A high percentage of germination and strong growth could be obtained in a culture solution containing 0.002 mol  $\text{MgCl}_2$ , while  $\text{CaCl}_2$  of the same concentration showed a marked toxicity.

Previous investigators have observed that pollen is very sensitive to various neutral salts. Germination is retarded, but its growth is stimulated by some of these salts. They considered these salts as injurious. No information, as far as the present author is aware, has heretofore been gained as to the probable relation between ions and the nature of the protoplasm of pollen.

## EXPERIMENT VIII.

This experiment was directed to find out the relation between the nature of the cation<sup>9)</sup> and the bursting of pollen<sup>10)</sup>).

A. Material: Pollen grains of *Lysichiton camtschatense*.

Culture solution: 0.01 mol sole solution of various salts.

Temperature: 21°C.

Observations were made after 2 hours' cultivation. Results are shown in Table XII.

B. Material: Pollen grains of *Lysichiton camtschatense*.

Culture solution: 0.001 mol sole solution of various salts.

Temperature: 21°C.

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9) The action of anions is in many cases accompanied by unequal concentrations of hydrogen-ions. These experiments were therefore confined to the action of cations.

10) The effect of cations on pollen germination will be treated in the next chapter.



Observations were made after 2 hours' cultivation. Results are shown in Table XIII.

C. Material: Pollen grains of *Impatiens Balsamina*.

Culture solution: 0.01 mol sole solution of various salts.

Temperature: 21°C.

Observations were made after 2 hours' cultivation. Results are shown in Table XIV.

TABLE XII.

Kind of salt		I	II	III	Average
KCl	Bursting (%)	72.1	83.8	76.3	77.4
	Germination (,,)	0.0	0.0	13.4	4.5
NaCl	Bursting (%)	64.2	81.1	89.3	78.2
	Germination (,,)	0.0	0.0	0.0	0.0
LiCl	Bursting (%)	47.5	49.0	53.3	49.9
	Germination (,,)	0.0	0.0	0.0	0.0
MgCl <sub>2</sub>	Bursting (%)	12.1	7.5	9.4	9.7
	Germination (,,)	0.0	0.0	0.0	0.0
SrCl <sub>2</sub>	Bursting (%)	0.0	0.0	0.0	0.0
	Germination (,,)	0.0	0.0	0.0	0.0
BaCl <sub>2</sub>	Bursting (%)	0.0	0.0	0.0	0.0
	Germination (,,)	0.0	0.0	0.0	0.0
CaCl <sub>2</sub>	Bursting (%)	0.6	0.0	0.0	0.2
	Germination (,,)	26.7	91.0	52.1	56.6
H <sub>2</sub> O	Bursting (%)	0.0	7.5	33.3	13.6
	Germination (,,)	22.0	51.3	13.3	28.9

TABLE XIII.

Kind of salt		I	II	III	Average
KCl	Bursting (%)	60.9	59.8	21.8	46.5
	Germination (,,)	10.1	11.6	37.1	19.6
NaCl	Bursting (%)	39.7	39.0	5.5	28.1
	Germination (,,)	23.8	51.2	26.0	33.7
LiCl	Bursting (%)	5.7	31.9	13.5	17.0
	Germination (,,)	0.0	10.1	0.0	3.4

TABLE XIII. —(Continued)

Kind of salt		I	II	III	Average
MgCl <sub>2</sub>	Bursting (%)	62.2	36.2	53.2	50.5
	Germination (,,)	15.1	23.0	29.5	22.5
SrCl <sub>2</sub>	Bursting (%)	0.0	0.5	0.0	0.2
	Germination (,,)	0.0	8.2	0.0	2.7
BaCl <sub>2</sub>	Bursting (%)	0.0	0.0	0.0	0.0
	Germination (,,)	0.0	0.0	0.0	0.0
CaCl <sub>2</sub>	Bursting (%)	3.0	2.1	0.0	1.7
	Germination (,,)	54.0	63.5	32.6	50.0
H <sub>2</sub> O	Bursting (%)	0.0	12.0	7.7	6.6
	Germination (,,)	14.4	31.4	50.4	32.1

TABLE XIV.

Kind of salt	pH value of sol.		I	II	III	Average
KCl	5.2	Bursting (%)	92.5	94.5	94.8	93.9
		Germination (,,)	0.0	0.7	0.0	0.2
NaCl	5.2	Bursting (%)	100.0	100.0	95.3	98.4
		Germination (,,)	0.0	0.0	0.0	0.0
LiCl	5.4	Bursting (%)	90.1	93.2	95.0	92.8
		Germination (,,)	0.0	0.0	0.0	0.0
MgCl <sub>2</sub>	5.2	Bursting (%)	60.4	59.8	67.4	62.5
		Germination (,,)	0.0	0.0	0.0	0.0
SrCl <sub>2</sub>	5.3	Bursting (%)	41.8	14.5	22.7	26.3
		Germination (,,)	0.0	0.0	0.0	0.0
BaCl <sub>2</sub>	5.2	Bursting (%)	0.0	0.0	0.0	0.0
		Germination (,,)	0.0	0.0	0.0	0.0
CaCl <sub>2</sub>	5.3	Bursting (%)	1.5	0.0	1.1	0.9
		Germination (,,)	20.6	8.0	14.1	14.2
H <sub>2</sub> O	5.2	Bursting (%)	1.3	0.0	3.1	1.5
		Germination (,,)	63.8	48.5	62.2	58.2

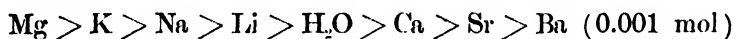
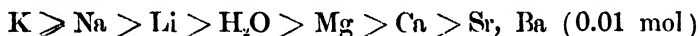
From these tables it can be recognized that the different influences of cations on the bursting and germination of pollen are sometimes not so outstanding and that the order of the strength of their effects is variable. As to the bursting of pollen, however, it can be generally

said that alkali metal salts have a stronger effect than alkali-earth metal salts. Cations can be arranged as follows, according to the strength of their effect upon bursting :

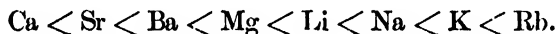
In the case of *Impatiens Balsamina*,



In *Lysichiton camtschatense*,



These series of ions resemble those of KAHHO (1920) which were determined in connection with injurious effects on red cabbage (i.e.,  $\text{K} > \text{Na} > \text{Li} > \text{Mg} > \text{Ba} > \text{Ca}$ ). TRÖNDLE (1918) has determined the order of the strength of effect of ions by means of the measurement of turgidity. His series is as follows :



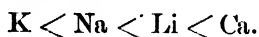
Again, KAHHO (1921) has obtained a like series of cations in the experiment of permeability of salts in *Lupinus* root.



In the case of *Lysichiton camtschatense* in 0.001 mol salt solution, the Mg-ion remarkably changed its position in the series. Analogous cases of change in the order of ions depending on the concentration of the salt, are known in SAKAMURA's work (1924) on the locomotive movement of *Gonium*.

HANSTEEN-CRANNER (1919) concluded that the penetration of salts can be regulated by the precipitation of lipid on the surface of cytoplasm. Therefore a strongly precipitating salt will make the outer membrane thick, and accordingly, it reaches the inside very slowly. That this thickening of the surface-colloid of cytoplasm has a moderate effect on the permeability of neutral salts has been observed by SPEK (1921) in the study of the effect of salts on the biocolloid of *Actinosphaerium*. He reached the conclusion that the precipitating and penetrating ability are inversely proportional (Abdichtungstheorie). The

higher the concentration of the salts, the higher is their power of penetration. The series of precipitating ability of cations of *Heliosoa* plasm has been determined as follows;



As shown in the works mentioned above, the permeability of neutral salts through plasma-membrane is reciprocally proportional to the precipitating ability of salts.

According to BENECKE (1907), when *Spirogyra* is transferred to a sole solution of  $MgSO_4$ , the cells are apart from each other, but the presence of a Ca-salt inhabits this phenomenon. LILLIE (1921) has observed that the gelatinous substance which covers the mass of eggs of *Asterias forbesi*, being insoluble in sea water, swells up and becomes soluble immediately after being transferred to an isotonic NaCl solution. On the other hand, when a small amount of  $CaCl_2$  was added to the solution of NaCl, the egg mass maintained its insolubility. Lillie explained this phenomenon by saying that plasma-colloid, especially its periphery, is in a water-insoluble condition, because of combining with Ca or like cations, but that when it is placed in a sole NaCl solution, it becomes a soluble compound through the replacing of the Ca, or like cations, by the Na-ion.

HANSTEEN-CRANNER (1914) interpreted the pathological phenomena, which appear in the cell membrane of the root of phanerogams in a sole K or Mg salt solution, as due the formation of water-soluble compounds of phosphatide or pectin substance with these cations.

SAKAMURA (1924) found that a *Gonium* colony, which is formed by 16 individuals in a gelatinous substance, was entirely dismembered in solutions of alkali-salts, and sometimes in a solution of Sr, Ba, or Mg salt. He agreed with the above mentioned authors in the explanation of this phenomenon.

From the foregoing facts, it will be seen that pectin and phosphatide, covering plasma-colloid or binding cells, change their solubility according to the cation combined with them. That is to say the character of the cations plays a very important rôle in the determination of the condi-

tions of biocolloidal substances. The intensity of the effect of the cations on the higher dispersion or swelling of colloidal substance must be parallel to their power of penetration. After all, with the cations which have great power of penetration the more the cytoplasm and intine are softened, the more the resistance of the plasma-surface decreases.

It is, therefore, a self-evident fact that the series of cations showing their decreasing effect on the bursting of the pollen grains coincides with that of their power to penetrate the cell walls.

### *3. Effects of some inorganic salts on pollen germination and its growth.*

According to the results of the foregoing experiments (Table XIII) we can see that the rate of the germination of the pollen grain depends in some degree upon the nature of the ions which act on the colloidal behavior of the protoplasm or the membrane substances. In the case of Sr, Ba, etc. the rate of both germination and bursting is low, because they act so as to retard the swelling of colloidal substances. In the case of K, Na, Mg, etc. the sum of the percentages of bursting and germination is large, though the germination itself is not so good, because they act so as to well colloidal substances.

## EXPERIMENT IX.

In this experiment, the effects of some sole salts on pollen, germination, and growth were studied. Pollen grains of *Hyacinthus orientalis* were cultured on an artificial culture medium of 1% agar containing 0.6 mol sucrose and 0.01 mol various salts. Measurements were made after 3 hours' cultivation at 25°C. Results are shown in Table XV, A and B.

TABLE XV.

A.

Kind of salt	pH value of medium	Number of pollen grains	Percentage of germination	Length of pollen-tube in $\mu$
Cont.	5.8	111	100	359.6
KCl	5.4	117	87.2	193.9
NaCl	5.8	122	92.6	239.9
LiCl	6.4	131	43.5	57.6
MgCl <sub>2</sub>	5.8	128	64.1	102.6
SrCl <sub>2</sub>	5.8	125	22.4	68.4
BaCl <sub>2</sub>	5.8	No germination		
CaCl <sub>2</sub>	5.8	137	85.4	355.0

B.

Kind of salt	pH value of medium	Number of pollen grains	Percentage of germination	Length of pollen-tube in $\mu$
Cont.	5.8	103	98.1	409.1
KCl	5.8	108	97.2	272.3
NaCl	5.8	111	98.2	322.2
LiCl	6.2	115	17.4	39.6
MgCl <sub>2</sub>	5.8	121	83.5	205.9
SrCl <sub>2</sub>	5.8	128	19.5	97.2
BaCl <sub>2</sub>	5.8	No germination		
CaCl <sub>2</sub>	5.8	124	88.7	370.6

As in these experiments the ground substance of the culture medium was prepared by using commercial agar, the pH value of the culture media could not always be made the same. Consequently, the results sometimes did not coincide with one another. The following series of cations is obtained, if they are arranged according to their effects on the rate of germination.

Cont.  $\geq$  Na  $>$  K  $>$  Ca  $>$  Mg  $>$  Li  $\geq$  Sr  $>$  Ba

When the bursting of the pollen is controlled by the addition of sugar and agar, the rate of germination in a medium containing an alkali-metal salt is better than that in the alkali-earth metal salt medium. The Li medium, however, showed an exceptional result, i.e., bad germination, probably due to its comparatively higher pH value as compared to the other media.

The following series of cations can be obtained regarding the effects on the rate of growth.

Cont.  $\geq$  Ca  $>$  Na  $>$  K  $>$  Mg  $>$  Sr  $>$  Li  $>$  Ba

Comparing this series with that of germination, there will be seen only one point of difference, that the Ca-ion changes its position, taking that next to the control culture, indicating the best growth in the salt media. The reason why such a change occurred may be explained by considering the nature of the Na- or K-ion, which promotes the bursting of the pollen grains. They not only stimulate the growth of the pollen-tube, but also increase the rate of bursting of the pollen-tube during its growth. In the case of Ca medium, the pollen-tube can grow slowly and steadily. Therefore, the rate of growth is slow in a K and Na, compared with that in a Ca, medium.

The effect of the Mg-ion on the bursting of the pollen grains is very strong, compared with K and Na, as shown in the experiments of the foregoing chapter (Tables XIII and XIV.), or rather stronger in some cases (Table XIII). In this experiment, (Table XV) however, the effect of the Mg-ion on the germination and the growth of the pollen-tube is always medium. The difference of these two results may be explained, as mentioned above, by the rate of the bursting of the pollen grains and the pollen-tubes during their germination and growth.

#### 4. Antagonism.

Many authors have observed the antagonism between Ca salt and various other salts in many physiological phenomena. This is, however,

very little known in the physiology of pollen. PARON (1921) found an agar medium containing  $\text{MgSO}_4$ ,  $\text{KCl}$ , and  $\text{FeSO}_4$  to be the best among the media he used for the pollen germination of several plant species. BRINK (1924) investigated the antagonistic action of Ca salt against Na or K salt on the growth on the sweet-pea pollen-tube. In the media of 0.01 mol  $\text{NaCl}$ +0.04 mol  $\text{CaCl}_2$ , 0.02 mol  $\text{KCl}$ +0.01 mol  $\text{CaCl}_2$ , 0.02 mol  $\text{KCl}$ +0.02 mol  $\text{CaCl}_2$ , and 0.04 mol  $\text{KCl}$ +0.01 mol  $\text{CaCl}_2$ , not only was the injurious effect of Na or K salt overcome, but the growth of the pollen-tube was 1.3-4 times as great as in the salt free medium.

As mentioned in the foregoing section (influence of cations on the bursting of pollen), monovalent cations act on the protoplasm-membrane, softening or making it less elastic, while the bivalent ones, as Ca, act contrarily, since the former penetrate the protoplasm more easily than do the latter. The control (salt free culture) stands between the alkalis and the alkali-earth-cations in the intensity of its effects. If we assume the control culture as the normal condition, the two groups of salts named above have quite opposite characters from each other. This fact can be seen in Tables XII and XIII in the present investigation and also in SAKAMURA's experiments (1924) with *Gonium pectinale*.

The following experiments were undertaken to see in what degree the antagonistic action among various salts occurs in the bursting and the germination of the pollen grain and also in the subsequent growth of the pollen-tube.

#### a. Antagonistic action of Ca-ion upon other cations.

In the present experiments the antagonistic action of the Ca-ion on the culture of the pollen grains is investigated.

### EXPERIMENT X.

In this experiment, the rate of bursting, the germination and the growth of the pollen tube of *Lysichiton camtschatense*, cultured in various salt solutions in the presence of  $\text{CaCl}_2$ , were observed. The concentration



of both salts in the mixture was 0.001 mol. Observations were made after 2 hours' cultivation at 21°C. Results are shown in Table XVI.

TABLE XVI.

Kind of salt	No. of experiment							
	I			II			Average	
	Burst. %	Germ. %	Growth %	Burst. %	Germ. %	Growth %	Burst. %	Germ. %
KCl	50.8	43.2	##	18.9	76.8	###	34.9	60.0
NaCl	5.9	84.3	++	3.1	84.4	+	4.5	84.4
LiCl	13.1	76.7	+	11.0	81.4	+	12.1	79.1
MgCl <sub>2</sub>	2.0	96.0	##	11.0	81.8	++	6.5	88.9
SrCl <sub>2</sub>	0.0	0.0		0.9	40.0	+	0.5	20.0
BaCl <sub>2</sub>	0.0	2.6	+	2.0	1.0	+	1.0	1.8
Cont. (CaCl <sub>2</sub> only)	0.6	75.6	+	0.0	65.5	+	0.3	70.6
H <sub>2</sub> O	10.5	37.9	+	6.7	66.7	++	8.6	52.3

The series of cations, according to their effect on the bursting of the pollen grains in *Lysichiton camtschatense*, using sole solutions of 0.001 mol, is

$$\text{Mg} > \text{K} > \text{Na} > \text{Li} > \text{H}_2\text{O} > \text{Ca} > \text{Sr} > \text{Ba}, \quad (1)$$

and on the pollen germination

$$\text{Ca} > \text{Na} > \text{H}_2\text{O} > \text{Mg} > \text{K} > \text{Li} > \text{Sr} > \text{Ba}. \quad (2)$$

As shown in Table XVI the presence of Ca-ions caused a depression of the rate of bursting and an augmentation of the rate of germination of pollen in every culture. According to the percentage of germination, a series can be arranged as follows:

$$\text{Mg} > \text{Na} > \text{Li} > \text{Cont. (Ca only)} > \text{K} > \text{H}_2\text{O} > \text{Sr} > \text{Ba}. \quad (3)$$

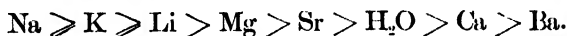
The last series is nearly the same as the series "1". Only one thing is different: The K-ion changes its position remarkably. This is

probably due to the rate of bursting which is larger than that in the case of other ions. With respect to the growth of the pollen-tube, considerably better results have been obtained with Mg- and K-ions than with the control or other salts solutions. Especially in the KCl solution much swelling took place, which naturally causes too quick growth and in the extreme cases accelerates the rate of bursting. In the latter case the percentage of germination decreased. A quickening of the rate of the germination can be seen by a comparison of the series "2" and "3". In the sole salt solutions the best germination was secured in the case of the Ca salt. In the presence of the Ca-ion the rates of germination in Mg, Na, and Li salt solutions surpassed that, not only in their solution, but also in the control culture (Ca salt only); the germination percentage was increased 4, 2.5, and 23 times respectively. (Compare Table XIII and XIV)

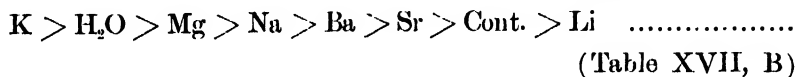
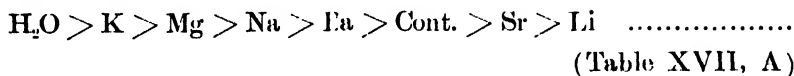
### EXPERIMENT XI.

In this experiment, the rate of bursting, the germination and the growth in pollen of *Impatiens Balsamina* cultured in various salt solutions in the presence of  $\text{CaCl}_2$  were observed. The concentration of each salt in the mixture was 0.01 mol. Observations were made after 2 hours' cultivation at 21°C. Results are shown in Table XVII, A and B.

The series of cations, according to their effect on the bursting of the pollen of *Impatiens Balsamina* in the case of the sole solution, is



The presence of the Ca-ion gave the following series of ions for the rate of germination :



In the presence of Ca, Li makes a remarkable change of its position in the series, and Na and Mg interchange their positions. The

TABLE XVII.

A.

Kind of salt	pH value of medium		No. of experiment			
			I	II	III	Average
KCl	5.5	Burst. Germ. Growth	21.2 78.8 ###	62.5 35.0 ###	80.0 12.6 ###	54.6 42.1 ###
NaCl	5.9	Burst. Germ. Growth	6.7 3.3 +	24.0 27.0 +	9.2 23.1 +	13.3 17.8 +
LiCl	6.0	Burst. Germ. Growth	72.9 6.2 +	78.4 0.0 +	92.0 0.0 +	81.1 2.1 +
MgCl <sub>2</sub>	5.6	Burst. Germ. Growth	51.9 28.8 #	81.5 16.9 #	8.9 30.4 #	47.4 25.4 #
SrCl <sub>2</sub>	5.7	Burst. Germ. Growth	0.6 1.8 +	0.0 2.2 +	0.0 4.2 +	0.2 2.7 +
BaCl <sub>2</sub>	5.6	Burst. Germ. Growth	2.0 3.0 +	0.9 2.7 +	3.4 20.3 +	2.1 8.7 +
Cont. (CaCl <sub>2</sub> only)	5.8	Burst. Germ. Growth	5.6 7.4 +	5.7 10.2 +	3.1 3.1 +	4.8 6.9 +
H <sub>2</sub> O	6.0	Burst. Germ. Growth	0.9 61.3 +	3.4 50.9 +	1.5 44.3 +	1.6 52.2 +

alteration of the position of Li may be due to the fact that the antagonistic effect of the Ca-ion against the Li-ion is not strong enough to secure a good germination. A Li salt + Ca salt solution shows the highest percentage of bursting. The change of the positions of Mg and Na can be explained by the fact that the antagonistic effect of the Ca-ion against the Mg-ion is greater than against the Na-ion. This is affirmed by the rate of growth.

TABLE XVII.

B.

Kind of salt	pH value of medium		No. of experiment			
			I	II	III	Average
KCl	5.4	Burst. Germ. Growth	7.2 73.9 ###	13.9 66.7 ###	7.7 65.5 ###	9.6 68.7 ###
NaCl	5.6	Burst. Germ. Growth	55.3 21.1 +	2.4 3.6 +	4.0 13.8 +	20.6 12.8 +
LiCl	6.0	Burst. Germ. Growth	58.1 4.7 +	30.3 4.0 +	68.8 0.0 +	52.4 2.9 +
MgCl <sub>2</sub>	5.3	Burst. Germ. Growth	0.0 23.8 +	33.7 40.3 +	10.0 42.5 +	14.9 35.5 +
SrCl <sub>2</sub>	5.9	Burst. Germ. Growth	0.0 0.0	0.0 4.1 +	0.0 11.4 +	0.0 5.2 +
BaCl <sub>2</sub>	5.7	Burst. Germ. Growth	0.0 4.3 +	12.1 12.1 +	10.0 4.2 +	7.4 6.9 +
Cont.	5.8	Burst. Germ. Growth	0.7 0.0 +	7.4 2.9 +	6.0 8.0 +	4.7 3.6 +
H <sub>2</sub> O	5.2	Burst. Germ. Growth	0.0 25.6 +	6.9 47.6 +	0.0 39.8 +	2.3 37.7 +

The pollen grain of *Impatiens Balsamina* is more sensitive to cations than that of *Lysichiton camtschatense*, and in sole salt solutions no germination (only a trace in K salt solution) can be secured, except in Ca salt solution. On the other hand, in the presence of the Ca-ion, all cases, except one case of Sr, show better germination than in the control culture. (Compare Tables XIV and XVII).

## EXPERIMENT XII.

In this experiment, pollen grains of *Hyacinthus orientalis* were cultured at 25°C. on an artificial medium of 1% agar containing 0.6 mol sucrose, 0.1 mol  $\text{CaCl}_2$  and various salts. The germination percentage and the length of the pollen-tube were measured after 3 hours' cultivation. Result are shown in Table XVIII, A, B, and C.

TABLE XVIII.

A.

Kind of salt	pH value of medium	Number of pollen grains	Percentage of germination	Length of pollen tube in $\mu$
Cont. I	6.0	113	95.6	446.9
Cont. II	5.6	161	63.4	302.0
KCl	5.6	100	100.0	434.7
NaCl	5.6	138	76.1	408.1
LiCl	5.6	140	77.1	294.3
$\text{MgCl}_2$	5.6	111	95.5	425.9
$\text{SrCl}_2$	5.6	138	76.8	196.2
$\text{BaCl}_2$	5.6	178	5.6	46.8

B.

Kind of salt	pH value of medium	Number of pollen grains	Percentage of germination	Length of pollen tube in $\mu$
Cont. I	6.0	210	95.5	498.8
Cont. II	5.6	139	76.3	292.0
KCl	5.7	106	98.1	469.3
NaCl	5.7	136	75.0	344.7
LiCl	5.9	171	29.3	92.5
$\text{MgCl}_2$	5.7	116	93.1	426.2
$\text{SrCl}_2$	5.9	149	34.9	113.0
$\text{BaCl}_2$	5.7	No germination		

## C.

Kind of salt	pH value of medium	Number of pollen grains	Percentage of germination	Length of pollen-tube in $\mu$
Cont. I	6.0	133	85.7	304.7
Cont. II	5.6	156	33.3	187.4
KCl	5.5	110	91.8	316.4
NaCl	5.4	173	59.5	253.4
LiCl	5.6	110	50.0	218.2
MgCl <sub>2</sub>	5.6	124	83.9	312.5
SrCl <sub>2</sub>	5.6	120	52.5	126.4
BaCl <sub>2</sub>	5.6	No germination		

Cont. I is a sucrose-agar medium without any salt.

Cont. II is a sucrose-agar medium with CaCl<sub>2</sub> only.

From the above tables we can get the following series of cations, arranged according to the rate of germination and growth in *Hyacinthus orientalis* :

For germination :

1. K > Cont. > Mg > Li > Sr > Na > Ca > Ba.....  
(Table XVIII, A)
2. K > Cont. > Mg > Ca > Na > Sr > Li > Ba.....  
(Table XVIII, B)
3. K > Cont. > Mg > Na > Sr > Li > Ca > Ba.....  
(Table XVIII, C)

For growth :

1. Cont. > K > Mg > Na > Ca > Li > Sr > Ba.....  
(Table XVIII, A)
2. Cont. > K > Mg > Na > Ca > Sr > Li > Ba.....  
(Table XVIII, B)
3. K > Mg > Cont. > Na > Li > Ca > Sr > Ba.....  
(Table XVIII, C)

In the case of the sole salt solutions the series of cations have already been mentioned, namely, for germination :

Cont.  $\succ Na > K > Ca > Mg > Li > Sr > Ba$ ,

and for growth :

Cont.  $\succ Ca > Na > K > Mg > Sr > Li > Ba$ .

The rate of germination in all cases, excepting Na and Ba, was improved by the addition of Ca salt. In the case of Na, there was a slight tendency to decrease. The K- and the Mg-ion show considerable antagonism in the presence of the Ca-ion and a much better growth than that in the case of the sole salt solutions. Also in Li and Sr better growth is obtained than in the sole solutions. (Compare Table XV and XVIII)

Summarizing the results with the three kinds of pollen, it can be said that the antagonistic effect of the Ca-ion is remarkably strong against the K- and the Mg-ion, but not so strong against the Na-, the Li- and Sr-ion.

#### b. The case in the presence of Sr- or Ba-ion.

Sr- and Ba-ion both of which have a chemical nature similar to that of Ca-ion, can be expected to show some similar results in antagonism.

### EXPERIMENT XIII.

The rates of bursting and the germination of the pollen grains of *Impatiens Balsamina* cultured in various salts solutions in the presence of  $SrCl_2$  were observed here. The concentration of both salts in the mixture was 0.01 mol. Observations were made after 2 hours' cultivation at 21°C. Results are shown in Table XIX.

TABLE XIX.

Kind of salt	pH value of sol.	No. of experiment					
		I		II		Average	
		Burst. (%)	Germ. (%)	Burst. (%)	Germ. (%)	Burst. (%)	Germ. (%)
KCl	5.2	0.0	1.3	0.0	3.2	0.0	2.3
NaCl	5.2	0.0	1.1	0.0	5.4	0.0	3.3
LiCl	5.4	0.0	1.8	0.0	26.6	0.0	14.2
MgCl <sub>2</sub>	5.5	0.0	1.6	0.0	4.6	0.0	3.1
Cont.	5.5	0.0	2.0	0.0	21.7	0.0	11.9
H <sub>2</sub> O	5.3	0.0	79.5	3.3	20.8	1.7	50.2

## EXPERIMENT XIV.

The rate of bursting and the germination of the pollen grains of *Lysichiton camtschatense* cultured in various salts solutions in the presence of SrCl<sub>2</sub> were observed. The concentration of both salts in the mixture was 0.001 mol. Observations were made after 2 hours' cultivation at 21°C. Results are shown in Table XX.

TABLE XX.

Kind of salt	No. of experiment					
	I		II		Average	
	Burst. (%)	Germ. (%)	Burst. (%)	Germ. (%)	Burst. (%)	Germ. (%)
KCl	8.6	81.9	14.3	78.6	11.5	80.3
NaCl	2.2	7.0	0.0	14.8	1.1	10.9
LiCl	0.0	23.3	0.0	15.8	0.0	19.6
MgCl <sub>2</sub>	1.9	44.2	0.0	31.7	1.0	38.0
Cont.	0.0	8.3	0.0	0.0	0.0	4.2
H <sub>2</sub> O	2.8	27.8	0.0	4.4	1.4	16.1



Generally the effect of these ions is to decrease both the bursting and the germination. This is due not to an injurious effect of the ions, but to their nature, which strongly lessens the swelling of colloid. This may be proved by the fact that better germination was secured in coexistence with the K-ion than in the case of sole salt. (Compare Tables XIII and XX, XIV, and XIX). BRINK's experiments (1924) also show that in a 0.001 mol solution of  $\text{SrCl}_2$  better growth was obtained than in a control culture (sugar solution only).

The Ba-ion has a stronger effect in reducing the bursting than the Sr-ion. (Tables XIII and XIV) Also in coexistence with other salts, it shows an excellent reducing effect. No bursting and germination could be obtained, although the ratio of the concentration of Ba salt to the others decreased from 1:1 to 3:7. However, it may not be due to an injurious effect of the ion, because the pollen grains kept their healthy appearance even after a day's culture. Definite conclusions as to this point must await further detailed experiments.

### c. Mutual effect between alkali-cations.

The antagonistic action between alkali-cations and alkali-earth cations has already been mentioned. The following experiments were made to learn the antagonistic action of alkali-cations upon each other.

## EXPERIMENT XV.

In this experiment, the mutual effect between alkali-cations on the culture of pollen grains was investigated, using a mixture of a pair of alkali-salts.

A. Material: Pollen grains of *Lysichiton camtschatense*.

Culture solution: A mixture of a pair of alkali salts, their concentration being 0.001 mol.

Temperature: 21°C.

Observations were made after 2 hours' cultivation.

Results are shown in Table XXI.

B. Material: Pollen grains of *Impatiens Balsamina*.

Culture solution: A mixture of a pair of alkali salts, their concentration being 0.01 mol.

Temperature: 21°C.

Observations were made after 2 hours' cultivation.

Results are shown in Table XXII.

C. Material: Pollen grains of *Hyacinthus orientalis*.

Culture medium: 1% agar containing 0.6 mol sucrose and a pair of alkali-salts, salt concentration being 0.01 mol.

Temperature: 25°C.

Observations were made after 3 hours' cultivation.

Results are shown in Table XXIII, A and B.

TABLE XXI.

		+LiCl	+NaCl	+KCl	Cont.
KCl	Burst. (%) Germ. (%)	55.8 7.3	40.0 56.0	91.3 7.0	20.9 7.0
NaCl	Burst. (%) Germ. (%)	21.0 14.3	17.8 64.0		
LiCl	Burst. (%) Germ. (%)	83.4 3.3			

TABLE XXIII.

	pH value of mixture		+LiCl	+NaCl	+KCl
KCl	5.3	Burst. (%) Germ. (%)	93.1 0.0	84.6 0.0	89.4 0.0
NaCl	5.1	Burst. (%) Germ. (%)	92.2 0.0	95.2 0.0	
LiCl	6.0	Burst. (%) Germ. (%)	91.8 0.0		
Cont.	5.2	Burst. (%) Germ. (%)	38.6 6.3		

TABLE XXIII.

## A.

Kind of salt	pH value of medium	Number of pollen grains	Percentage of germination	Length of pollen-tube in $\mu$
Cont.	6.0	104	97.1	508.9
KCl	6.0	104	99.0	392.9
KCl+NaCl	6.0	116	94.0	377.6
NaCl	6.0	113	93.8	338.6
NaCl+LiCl	6.0	153	73.2	120.2
LiCl	6.0	271	21.7	54.7

## B.

Kind of salt	pH value of medium	Number of pollen grains	Percentage of germination	Length of pollen-tube in $\mu$
Cont.	6.0	122	93.4	426.6
KCl	6.0	117	88.9	320.8
KCl+NaCl	6.0	106	95.3	334.3
NaCl	6.0	123	91.1	320.9
NaCl+LiCl	6.1	134	78.4	164.2
LiCl	6.1	197	27.4	57.2

As these results show, the antagonistic effect between alkali-cations is not generally so distinct, but somewhat better results are obtainable in the mixtures than in the sole salt solutions. Especially the combination of the K- and the Na-ion shows better germination in *Lysichiton camtschatense* and better growth in *Hyacinthus orientalis*.

After all, bivalent cations have shown antagonism to monovalent cations. Among cations of the same valency, the antagonism has also been obtained, as in Ca to Mg, and K to Na.

From the facts which have been shown in the investigations of other authors we can conclude as follows on the effect of the antagonistic

action between cations on the pollen germination: As bivalent cations act so as to solidify the plasma-membrane, they can completely or partially prevent the monovalent cations and themselves from penetrating into a pollen grain. On the other hand, the monovalent cations, as K, Na, and Li, have a tendency to liquefy the plasma-membrane and to penetrate it easily. Although we can classify the cations treated in the present experiments into two groups, monovalent and bivalent, it should not be overlooked that there are some differences among cations in the same group. In the salt mixture two or more kinds of cations react on the plasma-membrane, their effects compensating one another. They bring the membrane of a pollen grain into a favorable condition for germination and growth. This is a polar antagonism which generally takes place in plants.

## VI. Growth of Pollen-tubes.

### 1. Influence of Temperature.

Numerous investigations on physiological problems have been made in various temperatures by various authors, but only a few experiments on the subject of pollen-tube growth have been made in relation to temperature. VAN TIEGHEM (1869) reports 15°–25°C. as the favorable temperature for the germination of pollen in general. MOLISCH (1893) made his experiments on pollen germination at 18°C. SASAKI (1919) studied the effect of temperature on the germination of pollen and the growth of the pollen-tube with *Prunus Mume* and *Thea japonica* and reported 18°C. and 20°–21°C. respectively as the optimum temperatures. ZIEGLER and BRANSCHIEDT (1927) reported 20°–25°C. as the optimum temperature for the germination and growth of pollen-tubes in several fruit trees. BUCHHOLZ and BLAKESLEE (1927) made direct observations on the effect of temperature on the growth of the pollen-tubes of *Datura* within the pistil. The optimum temperature in this case was somewhere near 33.3°C. YASUDA and SATOW (1928) have tested the germination of the pollen of *Petunia violacea* at various temperatures. The best

germination in their experiments was obtained at 20°–23C°. The percentage of germination suddenly falls above and below this zone of temperature. These results of these germination tests show a coincidence with those of fruitfulness. If pollination was done in the summer when the atmospheric temperature was beyond the optimum for the germination of the pollen, the fertilization was considerably damaged. SHIBATA (1902) and DORSEY (1919) observed the temperature effects on fruitfulness by regarding the temperature effects on pollen-tube growth. The former reports 8°–10°C. as the minimum temperature for fertilization in *Monotropa* and the latter, 40°–50°F. in plum. Temperature relations might differ for different species, as shown by various authors. The results of the present author's experiments are next described.

#### EXPERIMENT XVI.

In this experiment, pollen grains of *Hyacinthus orientalis*, *Thea japonica* var. *spontanea*, and *Viola grypoceras* were cultured on a sucrose-agar medium at various temperatures, and the influence of temperature on the growth of pollen-tubes was investigated.

A. Material: Pollen grains of *Hyacinthus orientalis*.

Culture medium: 1% agar with 0.6 mol sucrose.

Measurements were made after 1.5 and 2.5 hours' cultivation.

Results are shown in Table XXIV.

B. Material: Pollen grains of *Thea japonica* var. *spontanéa*.

Culture medium: 1% agar with 0.2 mol sucrose.

Measurements were made after 2.5 hours' cultivation.

Results are shown in Table XXV.

C. Material: Pollen grains of *Viola grypaceras*.

Culture medium: 1% agar with 0.35 mol sucrose.

Measurements were made after 2.5 hours' cultivation.

Results are shown in Table XXVI.

TABLE XXIV. (See Fig. 5)

Temperature (C.)		7-8	20	25	30	35
Average length of pollen tubes in $\mu$	After 1.5 hours	—	189.5	393.8	526.0	87.2
	After 2.5 hours	58.8	569.8	818.5	865.5	104.1

Fig. 5. (Table XXIV)

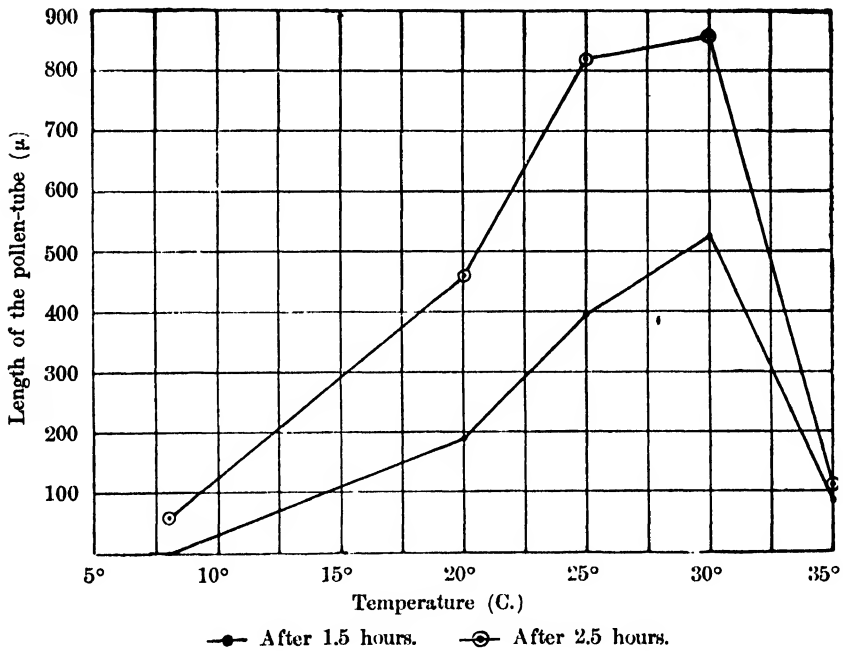


TABLE XXV. (See Fig. 6)

Temperature (C.)	10	15	20	25	30	34
Average length of 100 pollen tubes in $\mu$	107.7	383.5	645.4	818.7	152.1	Burst.

Fig. 6. (Table XXV)

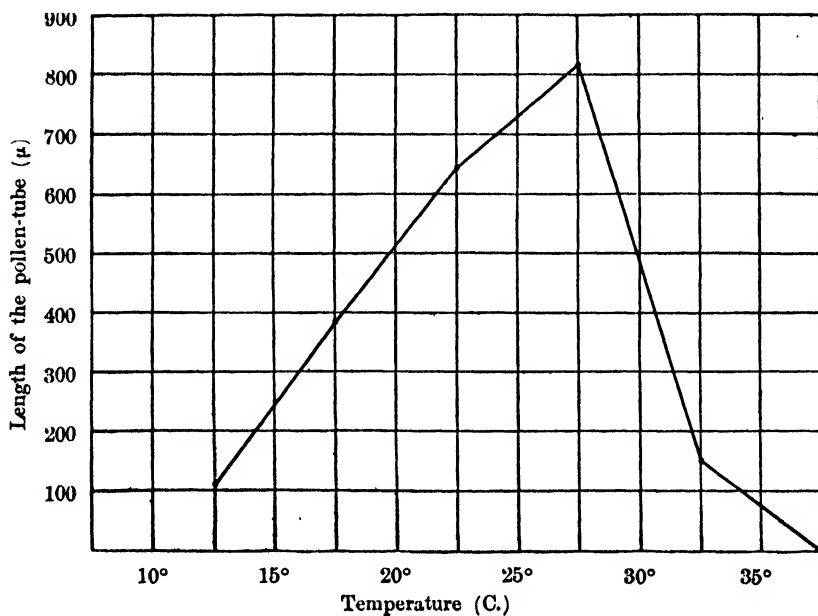
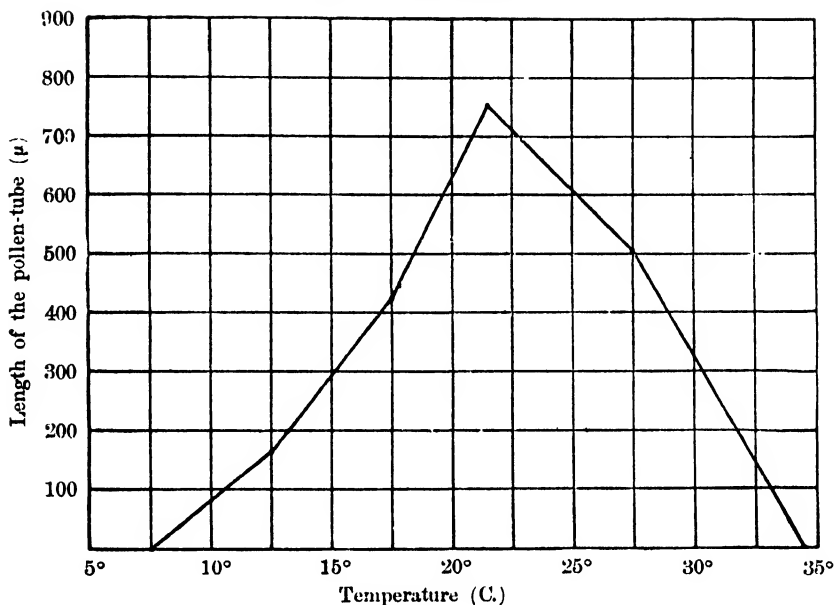


TABLE XXVI. (See Fig. 7)

Temperature (C.)	10	15	20	24	30	37
Average length of 100 pollen tubes in μ	—	166.0	428.1	751.7	502.7	Burst.

These results show that the temperature curve for the growth of the pollen-tube is generally, as in the case of fungi, slanting slowly to lower temperatures from the optimum temperature and quickly to higher temperatures. The optimum temperature varies for various plants. It seems that the optimum temperature for the growth of the pollen-tube has some relation to the flowering season of the plant. *Thea japonica* and *Viola grypoceras*, which bloom in the early spring, have an optimum temperature at about 25°C., and *Hyacinthus orientalis*, blooming in a warmer season, has it at about 30°C. The results of the above mentioned authors will support this assumption.

Fig. 7. (Table XXVI)



## 2. Growth Curve.

EAST and PARK (1918) studied the growth of the pollen-tube within the styler tissue in the *Nicotiana* species. The normal growth curve for the pollen-tube of *Datura* within the styler tissue obtained by BUCHHOLZ and BLACKESLEE (1927) did not show a resemblance to that of *Nicotiana* (EAST and PARK (1918)),  $\int$ -shape. The growth of the pollen-tube of *Datura* was expressed in a distinct straight-line after the first few hours. They assumed that acceleration of growth may be characteristic only of a plant showing self-sterility.

BRINK (1924) obtained an  $\int$ -curve for the growth of the pollen-tubes of *Vinca minor* and *Scilla* on artificial culture media.

## EXPERIMENT XVII.

In the following experiments growth curves were obtained for the pollen-tubes of *Hyacinthus orientalis*, *Viola grypoceras*, and *Lilium speciosum*. Measurements of the length of the pollen-tubes in the case of *Hyacinthus*



*orientalis* were made after staining with GUÉGUEN'S "lactic blue." GUÉGUEN (1901) used 0.75% and 0.5% cotton blue solutions in pure lactic acid for the staining of the pollen-tubes in the styler tissue. SNOW (1924) used this stain of the same concentrations to stain pollen-tubes of stocks in the styler tissue. According to the present writer's experience, a weaker solution, such as 0.1%, is better than a concentrated solution for staining pollen-tubes on an artificial culture medium. In the cases of *Viola grypoceras* and *Lilium speciosum* a few pollen-tubes were selected and their individual growth followed separately by measuring their length at definite intervals. Cultures were brought out of the thermostat during measurement, but for so short a time that the influence of the change of temperature was negligible.

- A. Material: Pollen grains of *Hyacinthus orientalis*.  
Culture medium: 1% agar with 0.7 mol sucrose.  
Temperature: 30°C.

Results are shown in Table XXVII.

- B. Material: Pollen grains of *Hyacinthus orientalis*.  
Culture medium: 1% agar with 0.7 mol sucrose.  
Temperature: 20°C.

Results are shown in Table XXVIII.

- C. Material: Pollen grains of *Viola grypoceras*.  
Culture medium: 1% agar with 0.35 mol sucrose.  
Temperature: 16 and 25°C.

Results are shown in Table XXIX.

- D. Material: Pollen grains of *Lilium speciosum*.  
Culture medium: 1% agar with 0.3 mol sucrose, without  
stigmatic secretion (A) and with stigmatic  
secretion (B).

Temperature: 25°C.

Results are shown in Table XXX.

TABLE XXVII. (See Fig. 8)

Time in hours	$\frac{2}{3}$	1.0	$1\frac{1}{2}$	$1\frac{2}{3}$	2	$2\frac{1}{2}$	3	4	5
Number of tubes measured	50	60	100	100	100	100	100	100	100
Average length in $\mu$	74.5	157.8	306.8	447.7	535.1	829.1	1028.2	1323.0	1487.7

TABLE XXVIII. (See Fig. 8)

Time in hours	1	$1\frac{1}{2}$	2.00	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	5	$5\frac{1}{2}$
Number of tubes measured		80	100	100	100	100	100	100	100
Average length in $\mu$	trace	87.7	184.6	385.4	567.3	623.6	858.1	1212.8	1402.4

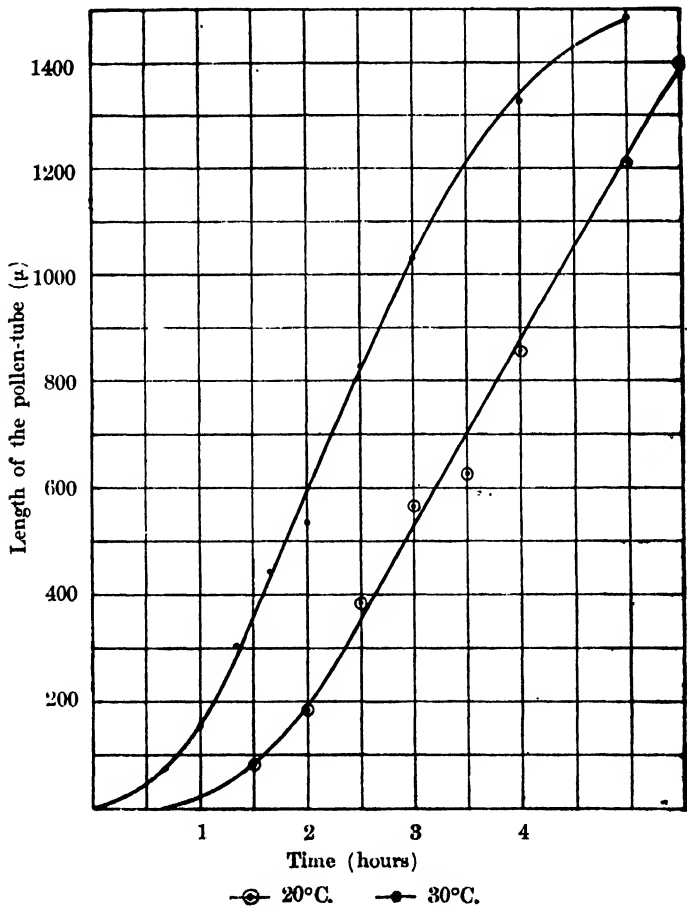
TABLE XXIX. (See Fig. 9)

Temp.	No. of pollen-tubes	Time in hours							
		1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	8
25°C.	1	139.2	383.0	600.0	835.0	992.0	1166.0	1235.0	1305.0
	2	95.7	278.0	490.0	696.0	800.0	1027.0	1218.0	1375.0
	3	87.0	261.0	487.0	696.0	818.0	1009.0	1148.0	1313.7
	Average	107.3	307.3	525.7	742.3	870.0	1067.3	1200.3	1331.2
16°C.	1	34.8	139.2	278.0	435.0	574.0	835.0	1920.7	1243.7
	2	19.4	87.0	174.0	296.0	418.0	660.0	835.0	1235.0
	3	17.4	87.0	156.6	278.0	400.0	557.0	835.0	1166.0
	Average	23.2	104.4	202.9	336.3	464.0	661.3	899.0	1214.9

TABLE XXX. (See Fig. 10)

Number of pollen-tubes	Culture medium	Time in hours						
		1	2	2½	3	4	5	6
1	A.	104.4	522.0	870.0	1678.8	1218.0	1305.0	1409.0
	B.	418.0	2001.0	2697.0	3567.0	4350.0	4700.0	4924.0
2	A.	87.0	261.0	522.0	974.0	1566.0	1879.0	2277.4
	B.	505.0	1966.0	2836.0	3880.0	5740.0	7407.0	7586.0

Fig. 8. (Table XXVII and XXVIII)



From the results of these experiments it can be said that also in these plants the pollen-tubes show an S-shaped growth curve at least in an artificial culture medium, though the gradient of the curve was different in different plants and was effected by such environmental conditions as temperature, contents of culture medium, etc. BRINK (1924) observed that the growth of pollen-tubes of *Vinca minor* was stimulated by the addition of a small amount of sterile yeast to the culture medium, whilst the gradient of the growth curve became steeper than that of the control culture.

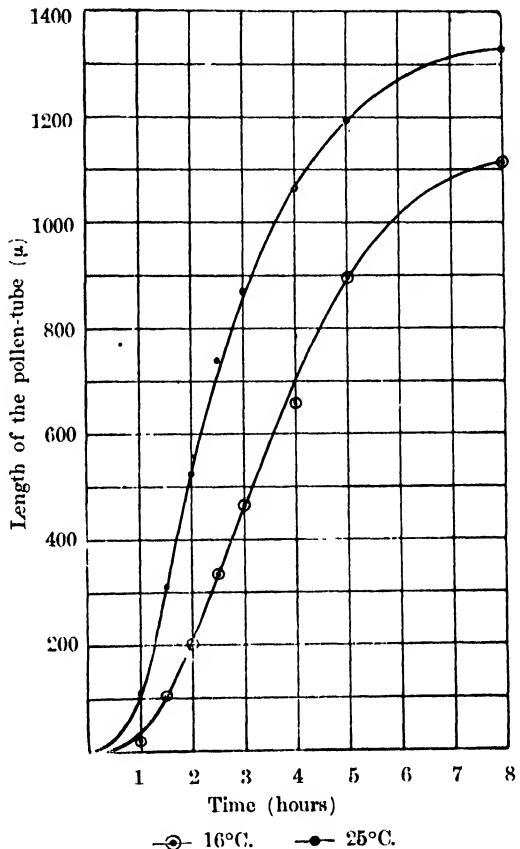
In the author's case of

*Lilium* pollen (Table XXX and Fig. 10) a remarkably steeper growth curve was obtained in a culture to which stigmatic secretion had been added. The maximum growth attained was about three times the length of that of the control culture in sugar-agar medium.

That the addition of living stigma or style, or their decoctions, to the culture medium stimulates the growth of the pollen-tube has been observed by various other authors.

There have been some instances where the length of the pollen-tubes cultured *in vitro* are comparable to those growing on the style of the plant. BOBILIOFF-PREISSER (1917) in *Vinca minor*, KNIGHT (1917)

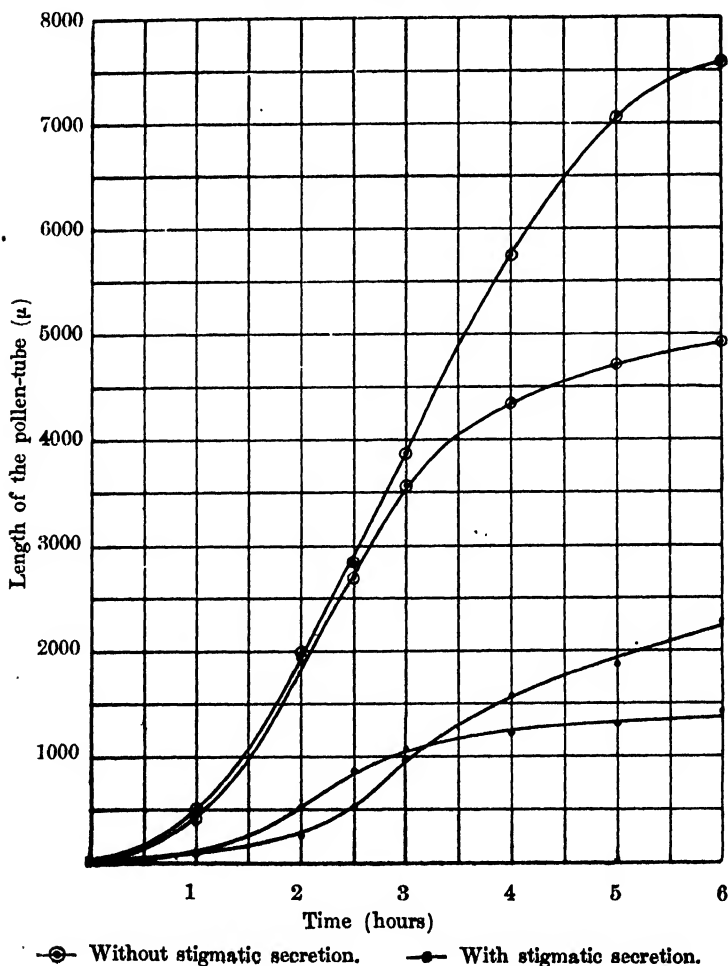
Fig. 9. (Table XXIX)



in apple pollen, and BRINK (1924) in *Vinca minor*, *Muscari botryoides*, *Puschkinia*, *Chionodoxa*, and *Schilla* on suitable artificial media secured pollen-tubes as long as the style.

In spite of these excellent instances it should still be said that the greater part of the growth of pollen tubes on an artificial medium occurs very slowly and the maximum growth in length is not so great as that on the style of the plant. Especially in a plant with a very long style this difference of growth will be seen distinctly. The length which the

Fig. 10. (Table XXX)



pollen-tube can attain in the manner of a nearly straight-line in the growth curve is variable with environmental conditions. In *Vinca minor* (BRINK, Text Fig. 3, 1924) a pollen-tube growing on a medium containing sterile yeast could become about twice as long as that on a yeast free medium without any diminution in the rate of growth. Results of the present experiment with *Lilium speciosum* (Table XXX) show a similar fact.

From these instances, it can be assumed that the growth of the pollen-tube in the stylar canal is under such suitable conditions that it can arrive at its destination, the ovary, before the appearance of the diminution of the rate of growth. Therefore the growth is shown in a straight-line curve in this case. An S-shaped growth curve may, however, be characteristic of the cases under less favorable conditions than the normal case on the style, i.e., on an artificial medium or in the case of a self-sterile plant, such as *Nicotiana*.

### 3. Relation to Polyploidy.

Comparative investigations on the nature of the pollen of various species in the same genus have been carried out in a few cases. MARTIN (1913) observed the different action of various sugars upon the pollen of some *Trifolium* species.

KIHARA (1923) worked on some physico-chemical natures of the pollen of various *Triticum* species with differing numbers of chromosomes, and found in these species different curves for the bursting of pollen at various hydrogen-ion concentrations of the culture media. KOBEL (1926), and ZIEGLER and BRANSCHIEDT (1927) studied the relation between the chromosome number and the rate of germination of the pollen of the apple and the pear, and considered that the rate of germination depends on the number of chromosomes, due to the abnormality in the reduction division.

## EXPERIMENT XVIII.

This experiment was made with the pollen of some garden varieties of *Hyacinthus orientalis* which have different numbers of chromosomes. According to DE MOHL's work (1921), the haploid number of *Hyacinthus orientalis* var. "Gigantea" is 12 and that of the var. "City of Haarlem" 23/2. *Hyacinthus orientalis*, which was used as control and of which the variety name was unknown to the author, has a bluish violet flower and 8 chromosomes as the haploid number. This chromosome number was determined by means of BELLING's iron-aceto-carmin method (1921) at the division of the generative nucleus in the pollen-tube.

In the experiment cultures were made on an artificial medium of 1% agar containing 0.6 mol sucrose and kept in an incubator at 25°C.

A. Material: Pollen grains of *Hyacinthus orientalis* and its variety "Gigantea".

Measurements were made after 2 hours' cultivation.

Results are shown in Table XXXI.

B. . Material: Pollen grains of *Hyacinthus orientalis* and its variety "City of Haarlem".

Measurements were made after 4 hours' cultivation.

Results are shown in Table XXXII.

TABLE XXXI.

Name of plant	Number of chromosomes	Number of pollen-tubes measured	Average length of tubes (in $\mu$ )
<i>H. orientalis</i>	8	81	245.7
<i>H. o.</i> var. "Gigantea"	12	85	331.4

TABLE XXXII.

Name of plant	Number of chromosomes	Number of pollen-tubes measured	Average length of tubes (in $\mu$ )
<i>H. orientalis</i>	8	81	449.6
<i>H. o.</i> var "City of Haarlem"	23/2	90	624.7

These results show that the rate of growth of *Hyacinthus* pollen depends on its chromosome numbers. That is to say, with the multiplication of the number of chromosomes a more vigorous growth appears. The pollen-tube of the triploid variety (var. "Gigantea") and a variety having a chromosome number nearly that large,  $23/2$  (var. "City of Haarlem"), showed about 30% faster growth than that of the diploid species.

In the next experiment, studies on the germination of pollen and the growth of the pollen-tube in various species of *Trifolium* were made. The chromosome number of the *Trifolium* species was determined by KARPETSCHENKO (1925), BLEIER (1925), and ERITH (1925). Materials which were used in the present experiments are as follows:

	Number of chromosomes
<i>Trifolium incanatum</i>	7
<i>T. hybridum</i>	8
<i>T. pannonicum</i>	ca. 65 (KARPETSCHENKO)
	ca. 48-49 (BLEIER)
<i>T. pratense</i>	8
<i>T. repens</i>	16 (ERITH and KARPETSCHENKO)
	14 (BLEIER)

The numbers tabulated above show the relation of polyploidy among some of these species.

## EXPERIMENT XIX.

In this experiment, the rate of germination of the pollen grain and the growth of the pollen tubes in various species of *Trifolium* cultured at 20°C. on a 1% agar medium containing various sugars was studied. Results are shown in Table XXXIII and XXXIV.



TABLE XXXIII.

Conc. of sugar (in mol)	Kind of sugar		<i>T. incan.</i>	<i>hybrid</i>	<i>pannon.</i>	<i>pratense</i>	<i>repens</i>
0.731	Sucrose	Germ.	Burst	+++++	+++	+	+++++
		Growth		× ×	× × ×	×	× ×
	Galactose	Germ.	Burst	+++++	+++	Burst	+++
		Growth		×	× × ×		×
0.877	Sucrose	Germ.	Burst	+++++	+++	++	+++++
		Growth		×	× ×	×	×
	Galactose	Germ.	Burst	+++++	+++	Burst	+++++
		Growth		×	× ×		×

"+" About 20% germination.

"×" Length of about 200  $\mu$ .

TABLE XXXIV.

Kind of sugar*	pH value		<i>T. incan.</i>	<i>hybrid</i>	<i>pannon.</i>	<i>pratense</i>	<i>repens</i>
Arabinose	5.6	Germ.	Burst	ca. 50% burst	Burst	Burst	ca. 50% burst
		Growth		×			
Glucose	6.0	Germ.	Burst	+++	+	Burst	+
		Growth		×	× ×		×
Fructose	5.4	Germ.	Burst	ca. 60% burst	Burst	Burst	ca. 50% burst
		Growth					

TABLE XXXIV.—(Continued)

Kind of Sugar*	pH value		<i>T. incan.</i>	<i>hybrid</i>	<i>pannon.</i>	<i>pratense</i>	<i>repens</i>
Galactose	6.0	Germ.	Burst	+	+++	+	—
		Growth		×	×	×	—
Mannose	5.6	Germ.	Burst	ca. 50% burst	Burst	Burst	.
		Growth					
Sucrose	6.4	Germ.	Burst	+++++	++	+	+
		Growth		×	×	×	×
Maltose	5.6	Germ.	Burst	+++++	+	+	+
		Growth		×	×	×	×
Lactose	5.4	Germ.	Burst	++++	+	+	+
		Growth		×	×	×	×

\* Concentration of sugar is 0.731 mol.

"+" and "×" Same meaning as in Table XXXIII.

From these results it is clear that the rate of germination and the growth of the pollen-tubes are characteristic for every species, but do not display any particular relation to the number of chromosomes in *Trifolium*. Pollen-tubes of various *Trifolium* species show no more vigorous growth with an increase of the number of chromosomes, while in the case of *Hyacinthus* pollen it can be said that with the multiplication of the number of chromosomes a more vigorous growth appears. KIHARA's work on the pollen of the *Triticum* species (1923) shows that various species which have different numbers of chromosomes have a quite different physico-chemical character of the plasma-colloid. These facts will give an interpretation to the results concerning the growth of the pollen-tube and the number of chromosomes of the *Trifolium* species.

It may be not improbable that such a case as *Trifolium*, above mentioned, can be seen in the allo-polyploidy, while the regular relation between the growth of the pollen-tube and the number of chromosomes as seen in *Hyacinthus*, is characteristic of auto-polyploidy.

## VII. Nuclear Behavior.

Since AMICI's discovery of pollen-tubes on the stigma of a *Portulaca* (1823), many investigators have endeavoured to ascertain the relation between the pollen-tube and fertilization. Two opposing views were held until the clear investigation of the fertilization process by STRASBURGER (1884) was made. The one was "the origin of embryo in embryo-sac", which was held by AMICI (1824), BRONGNIART (1827), and HARTIG (1842). The other was "the origin of embryo from pollen-tube", held by SCHLEIDEN (1835) and SCHACHT (1850). STRASBURGER concluded this opposition by finding the true meaning of the pollen-tube. Since then it is an accepted fact that in angiosperms the pollen-tubes grow to the micropyle for the purpose of delivering the male nuclei into the egg-apparatus. There are two modi of formation of male nuclei in the pollen of angiosperm plants. In one the division of a generative nucleus to form two male nuclei occurs before the ripening of the pollen. In the other the first division in a pollen grain takes place before the ripening of the pollen, resulting in a vegetative nucleus and a generative cell. In the latter case the male nuclei are formed by the division of the generative nucleus in the pollen-tube. The time of the division of the generative nucleus seems to have no relation to the phylogenetic group of the plant. It may be variable even in the same genus or species. For example, CHAMBERLAIN (1897) found that in *Lilium tigrinum* the division often takes place in the pollen grain, but in *L. philadelphicum* rarely so, and that in the latter species it might occur either in the grain or in the tube at any time up to its completed growth.

In the latter mode of male nuclei formation, the migration of the nuclei out of the pollen grain takes place shortly after the germination

of the pollen. The vegetative nucleus is, as a rule, followed by the generative nucleus. The nuclei do not, however, maintain a regular distance between the tip of the pollen-tube and themselves. These distances are shown in the following table. In these experiments the observations were made after staining with BELLING'S iron-aceto-carminc alone or combined with "lactic blue".

## EXPERIMENT XX.

Pollen-tubes of *Hyacinthus orientalis* were cultured on a medium of 1% agar with 0.88 mol sucrose at 20°–21°C. Observations were made after 20 hours' cultivation. Results are shown in Table XXXV.

TABLE XXXV.

Pollen-tube	Length of pollen-tube (in $\mu$ )	Distance to vegetative nucleus from the tip of pollen-tube (in $\mu$ )	Distance to generative nucleus from the tip of pollen-tube (in $\mu$ )	Generative nucleus divided (+) or not (–)
a	1879	122	226	–
b	1792	139	8	–
c	1910	139	209)* 296)	+
d	2036	435	348	–
e	2090	261	418	–
f	1827	35	122	–
g	2440	435	539	–
h	1479	34	34	–
i	1997	261	1997	–
j	1979	331	400)* 505)	+
k	1740	1740	1740)* 1740)	+
l	2107	1253	400	–
m	2032	52	87	–
n	1392	1096	365	–
o	2297	2297	2297	–

\* Showing distance to each of two male nuclei from the tip of the pollen-tube.

From this table it can be seen that in some cases the generative nucleus is followed by the vegetative nucleus (reversed situation of nuclei), and sometimes they are situated side by side. Pollen of "b", "d", "l", and "n" illustrate the former case and "h", "k", and "o", the latter case. Note that in "k" and "o" the migration of the nuclei did not take place, in spite of the long growth of the pollen-tube.

### EXPERIMENT XXI.

In this experiment pollen tubes of *Hyacinthus orientalis* were cultured at 20°–21°C. on a medium of 1% agar containing 0.88 mol sucrose. After 20 hours' cultivation, the mutual relation of the position of the vegetative and the generative nuclei was observed. Results are shown in Table XXXVI.

TABLE XXVI.

Culture	Total number of tested pollen-tubes	Number of pollen-tubes in which vegetative nucleus is followed by generative nucleus	Number of pollen-tubes in which vegetative nucleus is situated beside generative nucleus or between male nuclei	Number of pollen-tubes in which generative nucleus or male nuclei is followed by vegetative nucleus	Percentage of reversed position of the nuclei
a	181	142	4	35	19.3
b	206	143		63	30.6
c	179	124		55	30.7
d	228	150	1	77	33.8
e	321	219		102	31.8
f	211	143	7	61	28.9
g	215	146	4	65	30.2
Total	1541	1067	16	458	29.7 (Average)

From Table XXXVI it can be seen that the reversed situation of

the nuclei took place in rather a high percentage, at least in the pollen-tubes in an artificial culture.

The pollen of *Hyacinthus* with 8 chromosomes used to develop one pollen-tube. But the pollen of *Hyacinthus* with 12 chromosomes or nearly so, often germinates with two pollen-tubes. In such case, the one pollen-tube into which the nuclei migrated made normal growth and the other one, having no nucleus, ceased its growth sooner or later. Sometimes it could be observed that both pollen-tubes grew first to about equal lengths (Pl. I Fig. 1) or the latter could outgrow the former. (Pl. I. Fig. 2)

The division of the generative nucleus in the pollen-tube has been observed in many cases since STRASBURGER's investigation (1884). Above all, clear figures of metaphase can be seen in the publications of NAWASCHIN on *Lilium martagon* (1909) and of SAKAMURA and STOW on *Gagea lutea* (1926).

## EXPERIMENT XXII.

In this experiment, pollen-tubes of *Hyacinthus orientalis* were cultured at 20–21°C. on a medium of 1% agar containing sucrose of various concentrations, and the time relation of the division of the generative nucleus in the pollen-tube was studied. Results are shown in Table XXXVII.

TABLE XXXVII.

Culture	Culture medium		Duration of culture (in hours)	Number of pollen-tubes with two male nuclei	Number of pollen-tubes with a generative nucleus
	Agar (%)	Sucrose (mol)			
a	1	0.75	15.5	25	22
b	1	0.88	15.5	28	106
c	1	0.88	15.5	1	179
d	1	0.88	17.5	4	224
e	1	0.88	20.0	19	192
f	1	1.00	17.5	3	318
g	1	1.00	24.0	31	184

The results of these experiments show that this division may take place after about 16 hours' culture. The time of the division of the generative nucleus seems, however, to have a relation to the growth. The difference between cultures "a" and "b" may be due to the influence of the concentration of the sugar, and the difference between "b" and "c" to the age of the pollen.

### EXPERIMENT XXIII.

In this experiment, pollen-tubes of *Hyacinthus orientalis* were cultured at 20–21°C. on a medium of 1% agar containing sucrose of various concentrations. After about 16 hours' cultivation, observations were made and the relation between the time of the division of the generative nucleus and the concentration of the sugar in the culture medium was studied. Results are shown in Table XXXVIII.

TABLE XXXVIII.

No. of exp.	Culture media		Total number of tested pollen-tubes	Number of pollen-tubes with two male nuclei	Percentage of pollen-tubes with two male nuclei	Number of pollen-tubes with a generative nucleus
	Agar (%)	Sucrose (mol)				
I	1	0.75	111	70	0.63	41
	1	0.88	120	22	0.18	98
II	1	0.53	53	47	0.89	6
	1	0.88	140	18	0.13	122

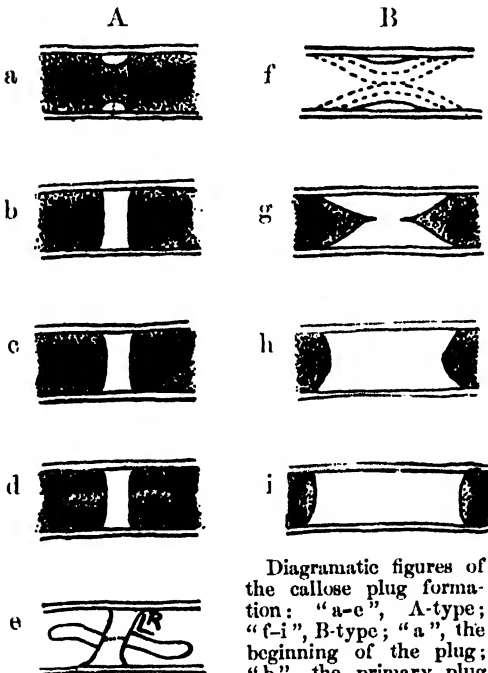
That the concentration of sugar in the culture medium has a considerable effect on the division of the generative nucleus in a pollen-tube is clearly shown in Table XXXVIII. The optimum concentration of sugar for the growth of the pollen-tube in *Hyacinthus orientalis* is about 0.2 mol in a 1% agar medium, and the rate of growth gradually decreases on both sides of this concentration. That is to say, a faster growth is obtained on the culture medium in the order of concentration

0.53, 0.75, and 0.88 mol of sucrose. The rate of division coincides with this order of fitness of the concentration of sugar in the culture medium to the growth of the pollen-tubes. Therefore we can say that as far as the concentration of sugar in the culture media is concerned, the better the growth of the pollen-tube, the faster the division of the generative nucleus takes place.

### VIII. Callose Plug.

The callose plug in the pollen-tube was first observed by STRASBURGER (1878). MANGIN (1890) stated that it is composed of callose. BOBILIOFF-

Fig. 11.



Diagrammatic figures of the callose plug formation: "a-e", A-type; "f-i", B-type; "a", the beginning of the plug; "b", the primary plug formation completed; "c", the beginning of the callose protrusion; "d", a complete callose plug; "e", the callose protrusion growing at a right angle to the primary callose plug which is aslant to the pollen-tube wall; "f", the beginning of the plug, dotted line showing the course of its growth; "g" and "h", the course of further growth; "i", a complete callose plug.

PREISSER (1917) reported three formation modi. For convenience, the modus which was reported in *Lathyrus latifolius* will be designated as A-type, that of *Vinca minor* as B-type, and that of *Narcissus angustifolius* as C-type.

A-type represents a centripetal formation of the callose plug. It arises from around the wall of the pollen-tube, and is relatively thin. (Pl. I. Figs. 3 and 4<sup>''</sup>). The callose ring grows centripetally until the plug is completely formed, like a concave lens.

### EXPERIMENT XXIV.

This experiment was made in order to discover the thickness of the callose plug before

11) In the case of *Thea japonica* var. *spontanea*, its thickness lies between 9 and 21  $\mu$ , as is shown in Table XXXIX, while the diameter of the pollen-tube is about 20  $\mu$ .



and after its complete formation. For this purpose, pollen-tubes of *Thea japonica* var. *spontanea* were cultured on a medium of 1% agar containing 0.2 mol sucrose, and the thickness of the callose plugs was measured after 4 hours' culture and after one day's. Results are shown in Table XXXIX.

TABLE XXXIX.

Number of graduations*	3	4	5	6	7
Callose ring	32	50	16	2	
Primary plug	44	32	16	7	1

\* Each graduation is equal to 3  $\mu$ .

As the results clearly show, the callose ring, the original body of the callose plug, grows centripetally only, but does not thicken along the pollen-tube wall (Fig. 11). After the completion of the plug formation a callose protrusion arises from each side of its center. (Fig. 11 c-d and Pl. I. Fig. 4) According to the author's observations, the callose protrusion arises from the middle of the plug at right angles (Fig. 11 e) even if the plug has been set aslant to the pollen-tube wall. BOBILIOFF-PREISSER (1917) stated that the total length between the ends of the callose protrusions could reach 50  $\mu$  in *Lathyrus latifolius*. In the present writer's case of *Thea japonica* var. *spontanea* in one instance a total length of 90  $\mu$  was measured.

#### EXPERIMENT XXV.

In this experiment, pollen-tubes of *Thea japonica* var. *spontanea* were cultured on a medium of 1% agar containing 0.2 mol sucrose. Distances between the pollen grain, the callose plugs, and the tip of the pollen-tubes were measured after 4 hours' cultivation. It was also observed whether the plug was completed or not. Results are shown in Table XL.

TABLE XI.

Pollen-tube	Pollen grain to 1st plug (in $\mu$ )	1st plug to the second (in $\mu$ )	The 2nd to the third (in $\mu$ )	The last to the third (in $\mu$ )	Plug closed (+) or not (-)		
					1st	2nd	3rd
a	52.2	139.2	—	418.0	—	—	—
b	104.4	—	—	470.0	—	—	—
c	174.0	209.0	296.0	348.0	—	—	—
d	121.8	139.2	—	348.0	—	—	—
e	69.6	139.2	209.0	261.0	—	—	—
f	139.2	209.0	279.0	296.0	—	—	—
g	209.0	—	—	418.0	—	—	—
h	104.0	174.0	—	487.0	—	—	—
i	121.8	191.0	—	557.0	—	—	—
j	174.0	—	—	209.0	—	—	—

From the results it is clear that the beginning of the second plug, sometimes even the third one, appears long before the first one is completed. The distances from the pollen grain to the first plug and from the last one to the tip of the pollen-tube are variable, but those from the first to the second and from the second to the third are pretty regular. They are studied more in detail in the following experiment.

#### EXPERIMENT XXVI.

In this experiment, pollen-tubes of *Thea japonica* var. *spontanea* were cultured at 25°C. on a medium of 1% agar containing 0.2 mol sucrose, and the relation of the distance between the callose plugs in the pollen-tube was studied. Results are shown in Table XII.

From these tables it is clearly shown that the distance from one plug to the next one is remarkably increased as they approach the tip of pollen-tube. In the pollen-tube which forms an A-type plug, additional plugs are very rare. Sometimes we can observe an additional plug of the C-type growing near the germination pore.

TABLE XII.

## A. Distances between the first plugs and the second ones.

Culture	Number of graduations* of ocular micrometer							Total number
	8	10	12	14	16	18	20	
a	2	19	20	12	2	3	2	60
b		7	6	10	3			26
c	1	5	3	5	6	1	1	22
d		6	9	5	2	1		23
e	1	13	17	14	3	2		50
f	2	9	8	4	1			24
g	1	15	16	15	5	1		53
Total	7	74	79	65	22	8	3	258

Average length  $12.44 \pm 0.10$  $\sigma = 2.37$ 

## B. Distances between the second plugs and the third ones.

Culture	Number of graduations* of ocular micrometer												Total
	10	12	14	16	18	20	22	24	26	28	30	32	
a		2	5	6	13	10	10	2	5	2	3		58
b	1	2	4	4	4	2	3	4		2			26
c	1	—	1	3	2	4	4	1	1	2	2	1	22
d		3	7	2	3	4	3	1					23
e		1	2	9	9	11	6	7	5				50
f		4	5	4	3	4	2	—	1	1			24
g	1	1	4	6	12	10	6	5	4	2	1	1	53
Total	3	13	28	34	46	45	34	20	16	9	6	2	256

Average length  $19.50 \pm 0.19$  $\sigma = 4.55$

## C. Distances between the third plugs and the fourth ones.

Culture	Number of graduations* of ocular micrometer											Total number
	16	18	20	22	24	26	28	30	32	34	36	
a		1	1	2	2	7	6	4	4	2		29
b	2	1	1	3	1	1	1					10
c				1	1	—	4	1	1	—	1	9
d	2	1	3	1	6	1	1	4	2			21
e		1	—	1	3	4	1					10
f		1	2	1	3	—	2					9
g		1	2	1	1	—	2	2	2	—	1	12
Total	4	6	9	10	17	13	17	11	9	2	2	100

Average length  $25.32 \pm 0.31$  $\sigma=4.60$ \* Each graduation is equal to  $17.4\mu$ .

The B-type was found in *Vinea minor* by BOBILIOFF-PREISSER (1917). He believed that they arise from "an equally wide deposit of callose at two opposite places on the wall of the pollen-tube". BRINK (1924), however, observing the same material, stated that "as the ring of callose thickens and so forth". Though his citation of the work of BOBILIOFF-PREISSER is not correct, he could observe that the plugs were formed centripetally. At the beginning of the formation of a B-type plug it has a greater thickness than the diameter of the pollen-tube (Pl. II. Fig. 5), and it grows not only to the center but also along the long axis of the tube (Fig. 11 f). The edge of the plug is not so sharp as that of the A-type. The author can not decide clearly in the early stage whether it grows centripetally or by an equally wide deposition of callose at two opposite places on the wall of the pollen-tube. He can, however, recognize in the later stage that it might grow more or less centripetally. After shutting off the passage of cytoplasm, the plug continues its growth until both sides of the plug show a concave curvature (Fig. 11 h). A further deposit of callose results in the longitudinal extension of the

plug, which at last develops a convex curvature (Fig. 11 i). The thickness of the plug can be measured as about 4-5 times, sometimes 10 times, the diameter of the pollen-tube. In the cases of *Solanum Capsicastrum* and *Antirrhinum majus*, the plugs attain a thickness up to about 60  $\mu$  and 90  $\mu$  respectively. BOBILIOFF-PREISSER (1917) reported that in *Vinca minor* the callose plugs may develop at very regular intervals of 300  $\mu$ . The intervals between the callose plugs in *Antirrhinum majus* were observed in the following experiment.

### EXPERIMENT XXVII.

In this experiment, pollen-tubes of *Antirrhinum majus* were grown on a medium of 1% agar containing 0.5 mol sucrose in an incubator at 25°C. The distances between the pollen grain, the callose plugs, and the tip of the pollen-tube were measured after 24 hours' cultivation. It was also ascertained whether the plugs had closed the passage of cytoplasm or not. Results are shown in Table XLII.

TABLE XLII.

Pollen-tube	Pollen grain —1st plug (in $\mu$ )	1st-2nd (in $\mu$ )	2nd-3rd (in $\mu$ )	The last— the tip (in $\mu$ )	Plug closed (+) or not (-)		
					1st	2nd	3rd
a	365.0	400.0	—	278.0	+	+	
b	261.0	348.0	435.0	296.0	+	+	+
c	505.0	383.0	—	156.6	+	+	
d	209.0	305.0	470.0	365.0	+	+	+
e	261.0	331.0	—	505.0	+	+	
f	278.0	121.8	—	261.0	+	+	
g	313.0	244.0	—	574.0	+	+	
h	296.0	244.0	278.0	296.0	+	+	+
i	296.0	331.0	331.0	296.0	+	+	+
j	313.0	261.0	435.0	139.2	+	+	—

In Table XLIII it can be noted that sometimes the distance between the pollen grain and the first plug is larger than that between the first plug and the second one (pollen-tubes "c", "f", "g", etc.), but that the latter is greater than the former at times (pollen-tubes "a", "b", "d", etc.). These distances are not so widely different. The relation of the distances between the pollen grain and the callose plugs is studied more in detail in the following experiment.

### EXPERIMENT XXVIII.

In this experiment, pollen tubes of *Antirrhinum majus* were cultured on a medium of 1% agar containing 0.5 mol sucrose in an incubator of 25°C. Distances between the pollen grain and the callose plugs in the pollen-tube were measured after 24 hours' cultivation. Results are shown in Table XLIII.

TABLE XLIII.

#### A. Distances between the pollen grain and the first plug.

No. of culture	Number of graduations* of ocular micrometer											Total number
	10	12	14	16	18	20	22	24	26	28	30	
1			5	11	23	21	12	4	6			85
2	2	2	8	13	13	11	8	5	3	4	1	70
3	2	6	11	22	17	21	14	8				101
4	3	6	15	8	12	12	10	2	4	3	1	76
5	2	10	13	8	15	12	9	3	2	1		75
Total	9	24	52	62	83	77	53	22	15	8	2	407

Average length  $13.33 \pm 0.13$

$\sigma = 4.01$

\*Each graduation is equal to 17.4  $\mu$ .

## B. Distances between the first plugs and the second ones.

No. of culture	Number of graduations* of ocular micrometer												Total number
	8	10	12	14	16	18	20	22	24	26	28	30	
1	1	2	4	13	23	12	10	4	8	4	4		85
2	3	7	11	9	15	13	11	—	1				70
3	1	12	11	28	6	15	15	3	3	2	1	3	100
4	3	8	7	12	14	10	8	6	2	3	2	2	77
5	4	7	5	19	16	8	11	2	3				75
Total	12	36	38	81	74	58	55	15	17	9	7	5	407

Average length  $16.44 \pm 0.15$  $\sigma = 4.58$ 

## C. Distances between the second plugs and the third ones.

No. of culture	Number of graduation* of ocular micrometer										Total number
	6	8	10	12	14	16	18	20	22	24	
1	1	4	8	11	—	11	4	3	4	2	43
2	2	14	11	9	13	9	8	3	1	—	70
3	6	15	15	17	13	9	4	2	3	—	84
4	9	24	26	15	20	12	1	2	—	1	110
5	10	17	20	11	11	9	2	3	—	—	83
Total	28	74	80	63	57	50	19	13	8	3	395

Average length  $12.06 \pm 0.14$  $\sigma = 3.99$ \*Each graduation is equal to  $17.4 \mu$ .

From these results one may see a tendency toward a decrease in the intervals at which the callose plugs are laid down.

The observations of the present author agree with those of BOBILIOFF-PREISSER (1917) and of BRINK (1924) in *Vinca minor* that additional plugs continue to be formed at random between the completed plugs.

The additional plug formation makes it difficult to measure the intervals between the regular plugs.

In the B-type, a succeeding callose plug does not appear until the last one has completely closed.

The C-type plug formation, which was found in the pollen-tube of *Narcissus latifolius* by BOBILIOFF-PREISSER (1917), grows from one side of the pollen-tube membrane to the other. In the beginning of the formation, plugs grow in such various shapes, i.e., single, dichotomous, trifurcated, etc., that the final forms of the plugs are various. A single one grows into a plug of almost even thickness, forked ones into irregular forms. Many of the latter show an unequal thickness and some of them enclose a small amount of protoplasm within themselves.

The plug which has an unequal thickness seems to have grown from the thicker end, but we can sometimes recognize clearly the end from which it began by the growth-rings (Pl. II. Fig. 6). Although BOBILIOFF-PREISSER's diagrammatic figures (his fig. 7a) show the plug growing from the outer side wall of a curved portion of the pollen-tube, this type of callose plug has a tendency to arise from the inner side wall of the curved portion. This tendency is very strongly presented in the pollen-tube of *Clivia nobilis* (Pl. II. Figs. 6 and 7). This modus of callose plug formation reminds the author that sand is deposited at the convex side of a river curve, and it leads him to suppose that callose may be deposited at the portion where the current of cytoplasm becomes slow.

The modi of the callose plug formation are different in various species of plants. The following table shows the modi of the callose plug formation in pollen-tubes cultured artificially. These were confirmed in the present investigation as well as by previous authors.

#### TABLE XLIV.

The modus of the callose plug formation in different species.

A-type : *Lathyrus latifolius* (BOBILIOFF-PREISSER, 1917)

*Thea japonica* var. *spontanea* Makino



B-type : *Vinca minor* (BOBILIOFF-PREISSER, 1917, BRINK, 1924)

*Antirrhinum majus* L.

*Solanum capsicastrum* Link.

C-type : *Narcissus latifolius* (Bobilioff-Preisser, 1917)

*Narcissus Jonquilla* L.

*Amaryllis* sp.

*Clivia nobilis* Lindl.

*Gagea lutea* Ker.

*Trillium camtschaticum* Pall.

*Tradescantia virginica* L.

*Cryptanthus zonatus*

Additional plugs are formed in some species of the A- and the B-types.

Table XLIV shows that plants in the same family of the same genus have the same modus of callose plug formation. For instance, all plants of the monocotyledoneae, as far as the present author's experiment proved, follow the C-type modus of formation. This relation between the modus of the plug formation and the taxonomy of the plants needs further investigation.

The formation of the callose plugs can be interpreted teleologically in the following way. They shut off the tip of the pollen-tube from the pollen grain and from the older portion of the tube in order to center its activity in the apical portion of the tube, maintaining an accumulation of the protoplasm. BRINK (1924) discarded the grain side by cutting off the pollen-tube just at the callose plug on the side away from the tip, and observed that the remainder could grow freely after the operation. This experiment proved how completely the callose plug can divide off the apical portion of the tube as a separate cellular body isolated from the older portion of the pollen-tube.

In pollen-tubes of some species, for instance, in *Lathyrus odoratus*, *Chaenomeles cardinalis*, etc., the callose plug formation has been very little observed in artificial cultures. Instead of this callose plug formation a vacuole is formed which gradually swells up to push the protoplasm

forward to the growing tip of the tube. Late on, many small vacuoles with the same function appear in the cytoplasm. (Pl. II. Fig. 8).

As the callose plugs are formed in order to prevent the backward movement of the protoplasm to the older portion of the tube, they should be laid down after the nuclei have passed through that portion of the pollen-tube. Therefore the nuclei should always be in the apical portion of the pollen-tube, but some abnormal cases can be found in artificial cultures of pollen. In one pollen-tube of *Thea jayonica* var. *spontanea* two male nuclei were observed to have been shut out from the apical portion. (Pl. II. Fig. 9). It is very interesting to notice that the second section, which contained the nuclei, had a thicker content than that of the apical portion in this case, which is clearly shown in Fig. 20 by its deeper staining character. Another case was found in a pollen-tube of *Clivia nobilis*, where the generative nucleus was caught by a growing callose plug. (Pl. II. Fig. 10)

### IX. Chemotropism.

For the purpose of seeking an explanation for the direction of the pollen-tube in the pistil of the plant, a rather large number of experiments on the tropic reaction of the pollen-tube have been made. Above all, chemotropism, especially for its own stigma, has been observed in many cases.

CORRENS (1889) found chemotropism of the pollen-tube for the stigma in *Primula acaulis*.

MOLISCH (1893) found chemotropism of the pollen-tubes towards their own stigma in many species of plants (*Narcissus Tazetta*, *N. poeticus*, *Amaryllis* sp., *Azalea indica*, *Fritillaria imperialis*, *Clivia miniata*, *Hyacinthus orientalis*, *Rhododendron arboreum*, and *Vincetoxicum officinale*). Also he observed that the *Narcissus* pollen-tube showed a chemotropic reaction not only to its own style and other parts of the flower, but also to the stigma of *Ornithogalum umberatum* and *Wiegelia rosea*, and even to yeast. When he placed an ovule in a culture drop, having first washed it thoroughly with water, the pollen-tube of *N. poeticus* grew, especially on the micropyle

and funicles, after 5-6 hours. MOLISCH concluded that the direction of the growth of the pollen-tubes into the stylar canal must be decided by the chemotropic effect of a secretion of the female sexual organs, and that in many cases the negative aerotropism acts in the same way.

MİYOSHI (1894) found that various sugars, especially sucrose, were active agents in the chemotropism of the pollen-tube, and that its sensibility was ruled by WEBER's law. He observed that the cut end of the style of *Digitalis purpurea* being pollinate, some pollen-tubes grew into the style and their tips appeared at the stigma. These results made him conclude that the pollen-tube grows to the ovary along the line of the least resistance in the style.

From the facts that not only the stigma of *Narcissus*, but also a part of a vegetative organ, for instance a section of *Allium* root, exercises a strong chemotropic effect on the pollen-tube of *Narcissus Tazetta*, LIDFORSS (1899a) believed that the active substance of this phenomenon was widely distributed. From results of the experiments with diastase, egg-albumin, casein, etc. he came to the conclusion that the active substance in the chemotropism of the pollen-tube must be a protein.

TOKUGAWA (1914) confirmed both MIYOSHI's and LIDFORSS' experiments and classified pollen into two groups. The one is saccharo-chemotropic and the other is proteo-chemotropic. For instance, *Camellia* pollen, belonging to the former, was affected by various sugars (sucrose, glucose, levulose, and maltose), and the pollen of *Narcissus* and *Prunus*, belonging to the latter group, was attracted by many protein substances (albumin, casein, nuclein, etc.). TOKUGAWA also observed that a pollen-tube could grow in a reverse direction in the stylar canal and he supported MIYOSHI's assumption that the pollen-tube follows the line of least resistance in the style.

KNOWLTON (1922) observed that the pollen-tubes of *Antirrhinum* show marked chemotropism towards a piece of the stigma but not towards *Geranium* or *Petunia* stigmas. The same phenomenon can be observed in the pollen-tubes of *Pirus Malus*, although it is not so pronounced as with *Antirrhinum* pollen.

BRINK (1924) studied the chemotropism of pollen-tubes in many forms of plants, using various plant tissues, principally gynaeceum parts. Only in two species, *Antirrhinum* sp. and *Narcissus Tazetta*, could the chemotropic phenomenon be observed. They showed undoubted chemotropic reaction to their own stigmas, especially the pollen-tube of *Narcissus Tazetta* was remarkably attracted not only by the ovule but also by the placenta and by pieces of the epidermis from the internal wall of the carpel. From these results BRINK was inclined to believe that chemotropism could not be an important and necessary factor in directing the pollen-tube to the micropyle, because the ovule did not show a dominating attraction to pollen-tubes in the ovarian cavity. In the present investigation, the writer noticed that the chemotropically active substance secreted from the micropyle diffuses over the inner wall of the ovarian cavity. Therefore various parts of the ovarian cavity may have chemotropic power, though they do not produce their own chemotropic substances.

Examining the literature, we can see that the earlier authors have considered the chemotropic reaction of the pollen-tube towards stigmatic secretion as a cause in orientating the pollen-tube into the stylar canal, but there is no experimental proof for the assumption. Experiments on the relation between chemotropism and the orientation of the pollen-tube from the stigma to the ovule were made as follows.

### EXPERIMENT XXIX.

In this experiment the stigmatic tissue of *Lilium speciosum* was cut as demonstrated in Fig. 22a, and each piece placed separately on a culture medium (1% agar+0.3 mol sucrose "Merck extra pure"). The difference of the intensity of the chemotropic effect caused by various parts of the stigma was studied. Results are shown in Table XLV.

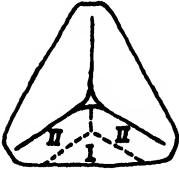
TABLE XLV.

Part of stigma	I	II
Intensity of chemotropism (Percentage of pollen-tubes attracted)	##*	+

\*+. expresses about 25%

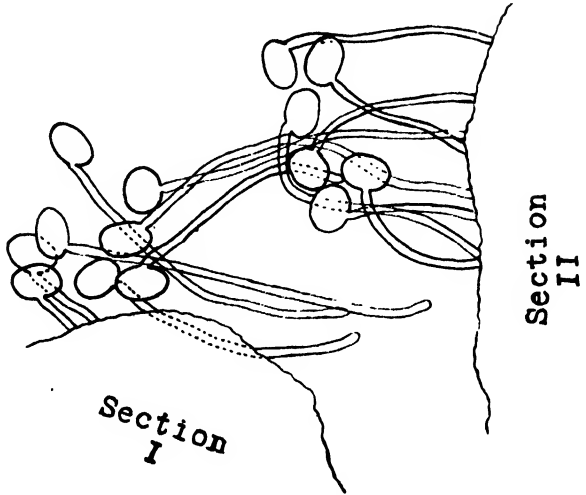
As shown in Table XIV, the nearer the tissue is to the touching part of the stigma lobes, the stronger the chemotropic effect.

Fig. 12a.



Diagrammatic figure of the projection of a stigmatic surface, dotted line showing the direction of the section.

Fig. 12b.



Showing chemotropism of the pollen-tube of *Lilium auratum* placed between section I and II of the stigma lobe of *L. auratum* (the position of the sections is shown in Fig. 12a.)

Pollen-tubes grow towards the touching part of the stigma lobes, which has a stronger attractive effect. This part is the entrance of

the stylar canal. When the pollen of *Lilium auratum* or *L. philippinense* was sown between the first and the second pieces of the stigmatic tissue of *L. auratum* (Fig. 12a), the pollen-tubes grew towards the second piece. (Fig. 12b) Therefore, it is obvious that the pollen-tube germinated on the stigma is conducted into the stylar canal by chemotropism.

### EXPERIMENT XXX.

In this experiment stigma, ovary, and various portions of style were sliced transversely, and placed on a culture medium. Pollen was sown around them. The intensity of the chemotropic effect was observed with results shown in Table XLVI and XLVII.

TABLE XLVI.

1. Stigma.
2. The uppermost part of the style.

3. A section of style at  $\frac{1}{4}$  the distance from stigma.
4. A section of style at  $\frac{1}{2}$  from stigma.
5. A section of style at  $\frac{3}{4}$  from stigma.
6. A section of the basal part of the style.
7. A section of the ovary.

(See Fig. 13)

Number given to gynaeceum part of <i>Lilium auratum</i>	Pollen-tubes		
	<i>L. longiflorum</i>	<i>L. auratum</i>	<i>L. Maximowiczii</i>
1	###	###	###
2	###	++	++
3	##	++	++
4	++	+	+
5	++	+	±
6	±	±	±
7	±	±	±

- ### More than 90% of the pollen-tubes were attracted.  
 ## More than 75% of the pollen-tubes were attracted.  
 ++ More than 50% of the pollen-tubes were attracted.  
 + More than 25% of the pollen-tubes were attracted.  
 ± Indifferent.

TABLE XLVII.

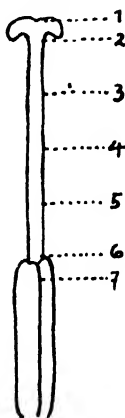
1. Stigma.
2. The uppermost part of the style.
3. A section of style at  $\frac{1}{4}$  the distance from stigma.
4. A section of style at its middle part.
5. A section of style at  $\frac{3}{4}$  the distance from stigma.
6. A section of the basal part of the style.
7. A section of the ovary.

(See Fig. 13)

Number given to gynaeceum part of <i>Lilium Maximowiczii</i>	Pollen tubes		
	<i>L. longiflorum</i>	<i>L. auratum</i>	<i>L. Maximowiczii</i>
1	###	++	++
2	###	++	++
3	###	++	++
4	###	++	++
5	###	+	++
6	##	+	+
7	+	±	±

From these results it can be recognized that in *L. auratum* the chemotropic effect of the style is considerably less than that of the stigma,

Fig. 13.



Diagrammatic figure of the gynaeceum part of *Lilium*, showing the position of sections used in the experiments.

but in *L. Maximowiczii* the effect is not so different. These phenomena vary also in various kinds of plants. Pollen-tubes of *L. longiflorum* show very strong chemotropism towards even a piece of the lower part of the style of *L. auratum* and *L. Maximowiczii*, but towards corresponding pieces, pollen-tubes of *L. auratum* and *L. Maximowiczii* show a very weak chemotropism.

From these results it cannot be said that the difference of intensity of the chemotropic effect in the stylar canal determines the direction of the growth of the pollen-tube, because it shows a decreasing tendency. The change of intensity of the chemotropic effect is so gradual, that the pollen-tube can grow along the line of least resistance in the style. If the intensity of the chemotropic effect of a part of a

#### EXPERIMENT XXXI.

In this experiment an attempt was made to find out the cause by which pollen-tubes grown into the ovarian cavity are directed to the micropyle.

Various gynaecium parts of *Zephyralhes candida* and its own pollen were used for the purpose. Cultures were made on a medium of 1% agar with 0.3 mol sucrose. The results are shown in Table XLVIII.

TABLE XLVIII.

Stigma	A section of ovary	Ovule	Inner wall of ovary
##	##	+	+

The present author cannot say if such a difference in the intensity of the chemotropic effect, as shown in Table XLVIII, can attract the pollen-tube to the ovule. It was, however, found that pollen-tubes growing around the micropyle showed clear chemotropism to only one point, i.e., the micropyle. This fact coincides with MOLISCH's observation in pollen-tubes of *Narcissus poeticus* when he placed the washed ovule on his medium.

Here the present author has to express his great regret that he could not get this historical material on experiments on chemotropism, as *Narcissus Tazetta*, in the course of his experiments. We may, however, assume that if the pieces of the gynaecium parts of *N. Tazetta* had been used after washing out in water in BRINK's experiment, some difference of the intensity of the chemotropic effect might have been observed among them. At least in the case of *Zephyralhes candida* we can say that pollen-tubes grown into the ovarian cavity are attracted to the micropyle by the chemotropic effect of a certain substance which is secreted around the micropyle.

The modification of the chemotropic effect of the gynaecium parts upon the pollen-tubes, due to the addition of stigmatic tissue to the culture medium, was studied in the following experiments.

#### EXPERIMENT XXXII.

The influence of the addition of stigmatic tissue of *Lilium Maximowiczii* to an artificial culture medium of 1% agar with 0.3 mol



sucrose on the chemotropic effect of pieces of various gynaecium parts of *Lilium auratum* was studied. Results are shown in Table XLIX.

TABLE XLIX.

Culture medium 1 : without the addition of stigmatic tissue.

2 : cooked with stigmatic tissue.

Pollen-tube	Medium	Stigma	Style	Ovary
<i>L. longiflorum</i>	1	###	+	±
	2	###	+	±
<i>L. auratum</i>	1	###	+	±
	2	###	+	±
<i>L. Maximowiczii</i>	1	##	±	±
	2	##	±	±

## EXPERIMENT XXXIII.

The influence of the addition of stigmatic tissue of *Lilium Maximowiczii* to an artificial culture medium of 1% agar with 0.3 mol sucrose on the chemotropic effect of pieces of various gynaecium parts of *Lilium Maximowiczii* was studied. Results are shown in Table L.

TABLE L.

Culture medium 1 : without the addition of stigmatic tissue.

2 : cooked with stigmatic tissue.

Pollen-tube	Medium	Stigma	Style	Ovary
<i>L. longiflorum</i>	1	+	###	±
	2	###	+	±
<i>L. auratum</i>	1	###	+	±
	2	##	+	±

TABLE I. -- (Continued)

Pollen-tube	Medium	Stigma	Style	Ovary
<i>L. Maximowiczii</i>	1	###	##	±
	2	###	##	+

From the results of these experiments shown in Tables XLIX and I, we can see the diminishing of the chemotropic reaction on the culture medium cooked with stigmatic tissue, more or less in the case with stylar tissue. In Table I it will be seen that pollen-tubes of *Lilium longiflorum* on the control culture medium show a weaker chemotropic reaction towards the stigmatic tissue than those on the culture medium cooked with the stigma of *L. Maximowiczii*. This may be due to the fact that the growth of the pollen-tube was remarkably worse in the former case than in the latter. Anyhow we can not see any remarkable difference in the effects of the two media.

## EXPERIMENT XXXIV.

In order to investigate the differences of intensity of the chemotropic effect according to the age of the flower, stigmas of *Lilium tigrinum* from flowers of different ages were used. A culture medium of 1% agar containing 0.3 mol sucrose was used. Results are shown in Table II.

TABLE II.

Age of stigma :

1. A day after bloom.
2. A few hours after bloom.
3. Immediately after bloom.
4. Not yet in bloom, petals a reddish orange color.
5. Not yet in bloom, petals an orange color.
6. Not yet in bloom, petals a yellowish green color.
7. Not yet in bloom, stigma a somewhat violet color.
8. Not yet in bloom, both stigma and style greenish.

sucrose on the chemotropic effect of pieces of various gynaecium parts of *Lilium auratum* was studied. Results are shown in Table XLIX.

TABLE XLIX.

Culture medium 1 : without the addition of stigmatic tissue.

2 : cooked with stigmatic tissue.

Pollen-tube	Medium	Stigma	Style	Ovary
<i>L. longiflorum</i>	1	###	++	±
	2	###	+	±
<i>L. auratum</i>	1	###	+	±
	2	###	+	±
<i>L. Maximowiczii</i>	1	##	±	±
	2	##	±	±

## EXPERIMENT XXXIII.

The influence of the addition of stigmatic tissue of *Lilium Maximowiczii* to an artificial culture medium of 1% agar with 0.3 mol sucrose on the chemotropic effect of pieces of various gynaecium parts of *Lilium Maximowiczii* was studied. Results are shown in Table L.

TABLE L.

Culture medium 1 : without the addition of stigmatic tissue.

2 : cooked with stigmatic tissue.

Pollen-tube	Medium	Stigma	Style	Ovary
<i>L. longiflorum</i>	1	++	###	±
	2	###	+	±
<i>L. auratum</i>	1	###	++	±
	2	##	++	±

TABLE I. -- (Continued)

Pollen-tube	Medium	Stigma	Style	Ovary
<i>L. Maximowiczii</i>	1	###	##	±
	2	###	##	±

From the results of these experiments shown in Tables XLIX and I, we can see the diminishing of the chemotropic reaction on the culture medium cooked with stigmatic tissue, more or less in the case with stylar tissue. In Table I, it will be seen that pollen-tubes of *Lilium longiflorum* on the control culture medium show a weaker chemotropic reaction towards the stigmatic tissue than those on the culture medium cooked with the stigma of *L. Maximowiczii*. This may be due to the fact that the growth of the pollen-tube was remarkably worse in the former case than in the latter. Anyhow we can not see any remarkable difference in the effects of the two media.

## EXPERIMENT XXXIV.

In order to investigate the differences of intensity of the chemotropic effect according to the age of the flower, stigmas of *Lilium tigrinum* from flowers of different ages were used. A culture medium of 1% agar containing 0.3 mol sucrose was used. Results are shown in Table II.

TABLE II.

Age of stigma :

1. A day after bloom.
2. A few hours after bloom.
3. Immediately after bloom.
4. Not yet in bloom, petals a reddish orange color.
5. Not yet in bloom, petals an orange color.
6. Not yet in bloom, petals a yellowish green color.
7. Not yet in bloom, stigma a somewhat violet color.
8. Not yet in bloom, both stigma and style greenish.

Age of stigma	Pollen-tubes		
	<i>L. longiflorum</i>	<i>L. auratum</i>	<i>L. Maximowiczii</i>
1	###	++	+
2	###	###	###
3	##	++	++
4	###	+	+
5	##	±	±
6	±	±	±
7	±	±	±
8	±	±	±

It is clear in this table that pollen-tubes of every species used in the experiment show the best tropic reaction to a piece of stigma from a flower a few hours after bloom, and less more or even to a piece taken one or two days before bloom. Equally strong chemotropism of the pollen-tubes of *L. longiflorum* towards the stigma of *L. tigrinum* is shown when its flowers are at ages of from a day or two before to a day after bloom, but their chemotropic effect on the pollen-tubes of *L. auratum* and *L. Maximowiczii* quickly decreases after and before the optimum age.

The surface of the stigma of *L. longiflorum* and *L. philippinense* is covered with white waxy slime until several hours after bloom, and then a transparent slimy secretion gradually takes its place. The chemotropic effect of the stigma of *L. longiflorum* in the above mentioned stages was compared in the following experiment.

#### EXPERIMENT XXXV.

The intensity of the chemotropic effect of the stigma of *Lilium longiflorum* in various stages on an artificial medium of 1% agar with 0.3 mol sucrose was studied in this experiment. Results are shown in Table LII.

TABLE LII.

Stage of stigma :

1. Stigma immediately after bloom, covered with white waxy slime.
2. Stigma a day after bloom, covered with transparent slimy secretion.
3. White waxy slime from stigma of stage 1.

Stage of stigma	Pollen-tubes			
	<i>L. longiflorum</i>	<i>L. auratum</i>	<i>L. Maximowiczii</i>	<i>L. speciosum</i>
1	± or +	± or +	± or +	± or +
2	≡	+	++	+
3	± or +	± or +	± or +	± or +

From the results the very interesting fact can be observed that the stigma of *Lilium longiflorum*, probably the same in *L. philippinense*, is covered with the waxy slime which has a more or less negative chemotropic effect towards the pollen-tubes of various *Lilium* species. It is very clear that the stigma is protected from pollination by the waxy slime for several hours after bloom. This is long enough to avoid self-pollination in the field, because the pollen of *Lilium* easily falls off from the anthers in a short time. It is a well known fact that some flowers are protected from self-pollination mechanically by various morphological structures. Such a physiological protection, however, has as far as the author is aware, not yet been mentioned.

## EXPERIMENT XXXVI.

The difference of the intensity of the chemotropic effect of the stigma and the chemotropic reaction of the pollen-tubes in various *Lilium* species was studied in this experiment. A culture medium of 1% agar containing 0.3 mol sucrose was used. Results are shown in Table LIII, A and B.

TABLE LIII.

A.

Stigma	Pollen-tubes			
	<i>L. longiflorum</i>	<i>L. auratum</i>	<i>L. Maximowiczii</i>	<i>L. speciosum</i>
<i>L. auratum</i>	###	###	###	###
<i>L. Maximowiczii</i>	###	++	++	+
<i>L. tigrinum</i>	###	##	###	+
<i>L. speciosum</i>	###	±	###	++

B.

Stigma	Pollen-tubes			
	<i>L. longiflorum</i>	<i>L. auratum</i>	<i>L. Maximowiczii</i>	<i>L. speciosum</i>
<i>L. auratum</i>	###	###	###	++
<i>L. Maximowiczii</i>	###	##	++	##
<i>L. tigrinum</i>	###	##	###	##
<i>L. speciosum</i>	###	+	+	+

In these tables it is shown that the intensity of the chemotropic effect of the stigma is the strongest in *Lilium auratum* and decreases in the order of: *Lilium tigrinum*, *L. Maximowiczii*, and *L. speciosum*, and that the chemotropic reaction of the pollen-tubes is the strongest in *L. longiflorum* and decreases in the order of: *L. Maximowiczii*, *L. auratum*, and *L. speciosum*. These results lead one to conclude that the intensity of the chemotropism of the pollen-tubes, at least in the *Lilium* species, is decided by the correlation between the chemotropic active substances of the stigma and the sensitiveness of the pollen to these substances.

### X. Artificial Culture of Gramineae Pollen.

It is an important problem in breeding technique to get some ideal methods for the artificial germination of the pollen of Gramineae plants, because to this group many important crop plants belong. It has been

well known, however, that it is a difficult matter to produce such germination on artificial media. Although some results positive to a certain degree were obtained by some authors, as JOST (1905), PFUNDT (1909), SASAKI (1919), KNOWLTON (1922), and others, the results could not be recognized as fully satisfactory, except in the case of corn pollen.

ELFVING (1879) used plain water, solutions of sugar (1% — thickness of syrup), ammonium tartrate, gum arabic, potassium nitrate, sodium carbonate, singly or mixed for this purpose. But his method was not successful.

LIDFORSS (1899) said that "der Pollen untersuchten Gramineen zeigt die Eigentümlichkeit, dass er unter keinen Umständen in künstlichen Nährlösungen zum Keimen gebracht werden kann".<sup>12)</sup>

The first positive result of artificial pollen germination in grass plants was reported by HANSGING (1897). He found that the pollen of *Phalaris brachystachya* germinates very well in pure water. However, he failed in the germination of the pollen of *Dactylis glomerata* and *Sesleria varia*.

JOST (1905) attempted to bring the pollen of Gramineae to germination by applying many chemicals in different concentrations, culture solutions with the living stigmas, leaf-decoctions (grasses), stigma-decoctions, or pressed juices of stigmas. These substances were used as stimulants to the germination of pollen. Although JOST's experiments did not bring any positive results, he found that only the pollen which lay near the culture-drops on the slide glass in a moist chamber germinated. This was observed in the pollen of *Dactylis*, *Arrhenatherum*, *Secale*, and *Glyceria*. From this fact he was convinced that the main condition for the germination was a moderate water supply. At last he succeeded in germinating a Gramineae pollen by using the leaf surface of a water plant and parchment paper. (See chapter II). By using boiled leaves he also proved that germination on the lower surface of the leaves was not the result of the influence of CO<sub>2</sub> gas. The pollen of *Secale cereale* was found very difficult to bring to germination and it only germinated occasionally on

12) He gave a note that "es wurden für die Versuche verschiedene Zuckerarten (Rohrzucker, Milchzucker, Traubenzucker, Fruchtzucker, Inulin, Galaktose u.s.w.) mit und ohne Zusatz von Säuren (Apfelsäure, Weinsäure, Citronensäure) benutzt".



a *Lymanthemum* leaf. On the other hand, germination of corn pollen was secured not only on parchment paper which was soaked with water or a 10% sugar solution, but also with an 8% agar as well as a 2%. In the case of *Tripsacum dactyloides*, pollen germinated quite as easily as the corn pollen. Pollen of *Zizania aquatica* does not germinate on any of those media. It germinates only on its own stigma. Pollen grains of *Poa annua* were found to germinate on agar, starch paste, and in a moist chamber.

PFUNDT (1909) studied the pollen of some grass plants, and he succeeded in the germination of pollen grains on sugar-agar-medium. The range of concentration of the sugar for the germination was generally not very wide<sup>13)</sup>, and at the optimum 20-30% germination was secured.

SASAKI (1919) made some experiments in this direction using young leaves of water plants, *Lymanthemum nymphaeoides* and *Hydrocharis asiatica*, for the germination of pollen of some cereal crop plants, but no germination was obtained. In the pollen of barley and rice, the agar in the medium was increased to 5%, but only a small amount of germination was obtained.

ANTHONY and HARLAN (1920) worked with barley pollen, and they obtained somewhat good results by using hog bladder.

The same kind of media as those of JUST and PFUNDT was used for the germination of corn pollen by ANDRONESCU (1915) and KNOWLTON (1922), only they changed the concentration. The last named author got the best germination result at that time (62%) on an 0.7% agar medium containing 15% sucrose.

ITAKURA (1922) proposed a new method and obtained somewhat better results with rye pollen.

TABATA, KIKUCHI, and SASAKI (1922) have studied very recently the pollen germination in several kinds of cereals and have secured remarkably better results than other workers. They used sucrose-agar medium in their experiments.

13) *Alopecurus pratensis* 15-40%, *Lolium perenne* 20-40%, *Poa Chaixii* 30-50%, *Secale cereale* 30-50%, *Zea Mays* 0-30%.

Although numerous investigations have been made, as above mentioned, we should recognize that the method of the artificial germination of Gramineae pollen has not been remarkably improved. Jost's results may be appreciated in some degree from the standpoint of their numerical value, but his method is more or less complicated and it is not desirable to use such animal or plant tissues. Unless they are used only for the purpose of proving that some kinds of pollen can germinate merely by mechanically, regulating the water supply or for another special purpose, we should prefer rather the stigma of the same plant itself. The difficulties of the treatment of the materials, non-uniformity of their textures, etc., have been already recognized by those authors. For instance, MARTIN (1913) studied *Trifolium pratense* pollen, using hog bladder, and said that it was not easy to dry the membrane so as always to secure good germination.

### 1. Control Cultures.

In the numerous experiments, mentioned above, the methods which gave more or less satisfactory results, except in the case of *Phalaris brachystachya* (HANSRIG, 1897), belong to the third and fifth group which were classified in the chapter on the historical review of the artificial germination of pollen. The methods of PFUNDT, ANDRONESCU, SASAKI, and KNOWLTON belong to the third group. The present author has described in an earlier preliminary paper (1924) and in a foregoing chapter how a very small amount of alkaline substance, which dissolves out of glass into the culture solution, has a great influence on the germination of pollen. However, as far as he is aware, most of the authors who occupied themselves with the experiments of pollen germination did not pay any attention to this important point. Therefore, before we discuss those methods and the results, we have to repeat some experiments with the same media that they used in order to compare with theirs.

For the sake of comparison, the results of the experiments with agar medium of the previous investigators are summarized in Table LIV.

TABLE I.IV.

Name of plant	Name of investigator	Year	Percent of agar	Percent of sugar	Percentage of germination
<i>Alopecurus pratensis</i>	PFUNDT	1909	1.0	30	20-30
<i>Avena sativa</i>	TABATA et al.	1929	1.0	30	36.6
<i>Coix lacryma</i>	TABATA et al.	1929	1.0	40	37.8
<i>Dactylis glomerata</i>	PFUNDT	1909	1.0	30-40	20-30
<i>Hordeum sativum</i> (Junrei)	SASAKI	1919	5.0	20	8.9
— (Fukkoku)	SASAKI	1919	5.0	20	12.3
	TABATA et al.	1927	1.0	30	12.6
<i>Lolium perenne</i>	PFUNDT	1909	1.0	30-40	20-30
<i>Oryza sativa</i>	SASAKI	1919	5.0	10	7.1
— (upland rice)	TABATA et al.	1929	1.0	15	64.5
— (paddy-rice)	TABATA et al.	1929	1.0	30	68.7
<i>Panicum Crus Galli</i> var. <i>Vurmentaceum</i>	TABATA et al.	1929	1.0	20	86.5
<i>Panicum miliaceum</i>	SASAKI	1919	1.0	20-30	1.0
—	TABATA et al.	1929	1.0	20	44.6
<i>Poa Chaizii</i>	PFUNDT	1909	1.0	40	20-30
<i>P. compressa</i>	PFUNDT	1909	1.0	30-40	20-40
<i>P. annua</i>	JOST	1905	8.0	0	?)
<i>Saccharinum officinarum</i>	DUTT & AYYAR	1928	0.7	26	3-61 <sup>2)</sup>
<i>Secale cereale</i>	PFUNDT	1909	1.0	40	20-30
<i>Setaria italica</i>	TABATA et al.	1929	1.0	20	59.6
<i>Triticum vulgare</i>	TABATA et al.	1929	1.0	10	35.5
<i>Zea Mays</i>	JOST	1905	8 & 2	0	?)
" "	PFUNDT	1909	1.0	15-20	20-30
" "	ANDRONESCUE	1915	0.7	10	20
" "	SASAKI	1919	1.0	20	4.9
" "	KNOWLTON	1922	0.7	15	62
" "	TABATA et al.	1929	1.0	20-30	49.7-62.6 <sup>2)</sup>

1) Jost did not give any numbers.

2) Different varieties show a different percentage of pollen germination.

## EXPERIMENT XXXVII.

\*In this experiment, method II was used. In order to compare the results of this experiment with those of previous investigators mentioned in Table LIV only a sucrose-agar medium was used without controlling the pH value. In the case of the species which had been investigated by previous workers, nearly the same concentrations of media were used. Results were shown in Table IV.

TABLE IV.

Name of plant	Concent. of agar	Concent. of sugar	pH value of med.	Number of pollen grains	Percent of germ.
<i>Alopecurus agrestis</i> (yellow anther)	0.5	0.5	6.9	473	28.8
	0.7	0.5	6.4	393	49.6
	1.0	0.4	6.8	218	69.3
	1.0	0.4	6.8	449	61.3
	1.0	0.5	6.2	269	51.7
<i>Alopecurus agrestis</i> (purple anther)	1.0	0.4	6.8	214	57.0
	1.0	0.4	6.8	338	81.7
	1.0	0.4	6.8	271	87.1
<i>A. fulvus</i>	1.0	0.4	6.8	200	77.5
<i>A. geniculatus</i>	1.0	0.5	6.2	326	45.7
	1.0	0.5	6.4	585	17.1
	1.0	0.6	6.4	375	60.0
<i>A. pratensis</i> (yellow anther)	1.0	0.5	6.0	332	32.2
	1.0	0.6	6.4	291	22.6
<i>A. pratensis</i> (purple anther)	1.0	0.5	6.0	388	75.8
	1.0	0.6	6.4	178	55.1

TABLE LV.—(Continued)

Name of plant	Concent. of agar	Concent. of sugar	pH value of med.	Number of pollen grains	Percent of germ.
<i>Anthoxanthum odoratum</i>	1.0	0.5	6.2	230	62.6
	1.0	0.5	6.4	450	67.1
	1.0	0.6	6.4	246	48.8
<i>Avena flavescens</i>	1.0	0.7	7.0	188	8.5
<i>Bromus inermis</i>	1.0	1.0	6.1	248	36.7
	1.0	1.1	6.5	478	40.2
<i>Cynosurus cristatus</i>	0.7	0.5	6.4	All burst	
	1.0	0.8	6.4	388	3.1
	1.0	0.9	6.7	575	10.1
	1.0	0.95	6.7	346	28.9
	1.0	1.0	6.1	568	21.2
<i>Festuca elatior</i>	1.0	0.7	7.0	448	11.6
	1.0	0.8	6.4	435	9.7
	1.0	0.9	6.7	198	21.2
	1.0	1.0	6.1	332	6.3
<i>Festuca elatior</i> subsp. <i>pratensis</i>	1.0	0.9	6.7	220	11.4
<i>Hordeum sativum</i> (two rowed)	1.0	0.8	6.8	277	17.7
<i>Hordeum sativum</i> (six rowed)	1.0	0.9	6.7	285	6.7
<i>Lolium perenne</i> (yellow anther)	1.0	0.9	6.7	473	10.1
	1.0	1.0	6.0	575	14.3
	1.0	1.1	6.5	518	29.0
	1.0	1.15	6.7	472	13.8

TABLE LV. - (Continued)

Name of plant	Concent. of agar	Concent. of sugar	pH value of med.	Number of pollen grains	Percent of germ.
<i>Lolium perenne</i> (purple anther)	1.0	1.0	6.0	218	5.5
	1.0	1.1	6.5	336	39.9
<i>Oryza sativa</i> (Akage)	1.0	0.3	7.0	132	24.2
<i>Panicum miliaceum</i>	0.7	0.45	6.5	All burst	
	1.0	0.5	6.5	58	40.7
<i>Phleum pratense</i>	1.0	0.4	6.8	176	33.0
<i>Secale cereale</i>	1.0	1.15	6.7	109	54.5
<i>Zea Mays</i> "Black Starch"	1.0	0.3	7.0	338	56.8
<i>Zea Mays</i> "Catowber"	0.7	0.45	5.8	160	55.0
	1.0	0.3	7.0	153	65.1
	1.0	0.3	7.0	163	71.2
<i>Zea Mays</i> "Large White Flint"	1.0	0.3	7.0	249	22.1
<i>Zea Mays</i> "Mammoth Sweet"	0.7	0.45	5.8	110	17.3
	1.0	0.3	7.0	78	11.5
	1.0	0.3	7.0	220	15.5
<i>Zea Mays</i> "Northwestern Dent"	1.0	0.3	7.0	181	19.3
	1.0	0.3	7.0	128	49.2
<i>Zea Mays</i> "Sweet Orange"	1.0	0.3	7.0	224	21.9
<i>Zea Mays</i> "White Ever Green"	1.0	0.3	7.0	288	14.6
	1.0	0.35	7.1	259	73.7

In these experiments plain sucrose-agar medium was used, of which the pH values varied from 5.9 to 7.1. This variation of the hydrogen-ion concentration may be caused by the different impurities of the agar, which could not be easily removed.

Corn pollen was known as a kind less sensitive to the water supply and as one which germinates more easily than other Gramineae pollen. According to JOST (1905) and PFUNDT (1909) it is possible to bring pollen grains of this plant to germination on agar-media containing 0.30 per cent sucrose. Summarizing the results of various workers, the optimum concentration is 0.7-1% agar plus 10-20% sucrose yielding a germination percentage between 4.5 and 62. KNOWLTON (1922) has shown by his experimental data (his table 4) that different concentrations of agar and sugar brought various results. Many other authors, however, must have made at least several experiments to decide the optimum concentration, so that it cannot be considered that those differences of results are due to the difference of the concentrations of the media. According to the writer's experiments (Table LV), the percentage of germination is remarkably variable according to the plant varieties, even on the medium which has, not only the same concentration of sugar and agar, but has also the same concentration of the hydrogen-ion. They vary from the lowest percentage in "Mammoth Sweet" (15.5%) to the highest in "White Ever Green" (73.7%). ANDERSON and KULP (1922) tabulated the difference of the contents of pollen among some varieties of corn as follows:

	Yellow dent	White flint	Pop-corn
Starch	11.07	19.04	18.03
Reducing sugar as dextrose	3.50	5.38	4.95
Sucrose	9.09	2.94	14.18
Ash	3.46	3.83	3.13

The difference in the contents, especially of sugar, may partially explain the difference of sensibility to the artificial medium for germination. From these facts the present author is convinced that KNOWLTON's

good results are not due to his choice of a more suitable concentration of the medium, but rather it might be his use of a variety suitable for the purpose, though he did not give the name of the variety of his material. The experiments of DUTT and AYYAR (1928) on the pollen of sugar cane affirm this assumption. The percentage of pollen germination varies from 3 to 61 according to the varieties of the plant.

In the cases of *Alopecurus agrestis*, *A. pratensis*, and *Lolium perenne* the pollen from a purple anther shows better germination than that of a yellow one. Further experiments are desirable on this aspect of the problem.

SASAKI's results in *Hordeum*, *Panicum*, *Oryza*, and *Zea* show relatively low percentages. This might be due to the quality of the glassware which he employed in his experiments. In an earlier chapter it has been already shown that a remarkable difference of germination was induced by the difference of the quality of the cover glass in the hanging-drop culture. In those experiments the change of the hydrogen-ion concentration of the culture drops could not be tested directly. In the present experiment, however, the pH value of the culture media can be determined, and the difference of their qualities noted.

### EXPERIMENT XXXVIII.

In this experiment, two kinds of sucrose-agar medium (1% agar and 0.5 mol sucrose) were used. The one was prepared in a non-alkaline glass flask and the other in an alkaline one. Rates of germination of the pollen grains and the growth of the pollen-tubes were observed. Results are shown Table LVI.

TABLE LVI.

Kind of medium	pH value of medium		<i>Alopecurus geniculatus</i>	<i>Alopecurus pratensis</i>	<i>Anthoxanthum odoratum</i>
A	6.4	Percentage of germination	17.1	28.5	67.1
		Growth rate	+++++	++	+++++



TABLE LVI.—(Continued)

Kind of medium	pH value of medium		<i>Alopecurus geniculatus</i>	<i>Alopecurus pratensis</i>	<i>Anthoxanthum odoratum</i>
B	7.6	Percentage of germination	4.5	12.0	23.7
		Growth rate	++	+	+

As the results show, the difference of the quality of the glass of the flask in which the media were prepared affected the pH value of the media, and gave pH 6.4 and pH 7.6. Such a difference of the pH value can be expected to be the cause of remarkably different results in germination and growth.

## 2. Relation between the Germination and the Dryness of the Pollen.

In the germination of pollen, the function of some kinds of stigma which do not produce any special secretion is to regulate the water supply. This view was held by many investigators, such as JOST, MARTIN, and others who studied this point. MARTIN (1913) said that "if this is the function of the stigma, and the water supply must be as delicately adjusted on the stigma as on the membrane to secure germination, the conditions which will modify the amount of water delivered by the stigma have an effect on fertilization". And again he said that "if germination depends upon a certain balance between the amount of water taken up and transpiration, then a variation in the moisture of the atmosphere would have an effect on fertilization". It is very clear that the factors which act on the water balance in this case are the nature of the stigma, the atmosphere, and the dryness and number of pollen grains which are pollinated on the stigma.

MARTIN (1915) made comparative experiments with alfalfa pollen on the inter-related influence on germination of moisture in the air and in the medium. He found that when the moisture of the substratum is less, better germination is secured in air with more moisture, and vice versa.

For instance, with tin foil, the best germination was obtained over pure water or in approximately 100 per cent atmospheric moisture, and with moist bladder good germination resulted in air with a moisture content ranging from 81.8 to 63.1 per cent.

In the case of pollen germination on the stigmatic surface of the Gramineae plant, the movement of water between the stigmatic tissue and the pollen grain is a similar phenomenon. So the dryness of the pollen will have an influence on the velocity of the transfer of enough water for germination from the stigmatic tissue to the pollen grain. It is, however, clear that an artificial culture medium can not provide such a complex system as the structure of a cell. Accordingly, it is difficult from the present knowledge in this direction to get an artificial medium which can not only regulate the water supply, as in a stigmatic tissue, but which also has a suitable texture for microscopic observation. On the contrary, we can control the dryness of pollen grains. As mentioned in descriptions of the morphological character of pollen grains, they can be divided into two types by their appearance of turgidity at the instant of the dehiscence of anthers; the one has more or less shrinkage and the other has not. The former seems to germinate easier than the latter on an artificial medium. On this account, this matter of the dryness of the pollen grains may be an important point in the investigation of the artificial germination of Gramineae pollen.

The dryness of pollen has never, as far as the writer is aware, been considered in the case of germination on an artificial medium. Methods which have been used up to date were almost all, except several cases for some special purpose, carried out in a closed air chamber and with fresh pollen. In the following experiments, the open method II was used, where the pollen grains were spread on the medium 20 minutes after its preparation. They were not covered. Therefore a certain degree of evaporation from the medium occurred, which was accompanied by a slight change of the concentration of the medium. Pollen grains were gathered on a clean glass plate or on a sheet of paraffin paper, and after being left on a table in the laboratory, a certain amount of them were

sown on the medium at different intervals. Commercial sugar is more suitable than chemically pure sugar for the purpose of germination. It is clearly shown in BRINK'S work (1924) that better germination and growth of *Cucumis* pollen resulted on a commercial sugar than on a chemically pure sugar medium.

Beet sugar (Hokkaido Seito Co.) was used for the present experiments.

### EXPERIMENT XXXIX.

In this experiment, the relation between the time of exposure of the pollen grains in the air and the rate of germination and bursting of the pollen in several Gramineae plants was under observation. Results are shown in Table LVII.

TABLE LVII.

Plant name	Medium				Time of exposure in the air					
	Agar	Sugar	pH		0.0	0.5	1.0	1.5	2.0	2.5
<i>Festuca eactor</i>	1.0	0.85	6.9	Germ. Burst.	7.6 46.8		29.4 20.0		64.4 2.5	
<i>Alopecurus</i> (purple anther)	1.0	0.4	6.8	Germ. Burst.	87.1 11.4	92.1 3.4				
<i>Hordeum sativum</i> (two rows)	1.0	0.9	6.7	Germ. Burst.	8.2 4.7		34.2 3.7			
<i>Secale cereale</i>	1.0	1.0	6.8	Germ. Burst.			56.4 22.8	76.7 9.2		95.0 1.0
<i>Zea Mays</i> "Catowber"	0.7	0.45	5.8	Germ. Burst.	55.0 12.5	59.0 2.3	81.3 4.1	89.3 0.0	64.7 0.0	

Germ. Germination percentage.

Burst. Bursting percentage.

From these results very interesting facts are found. One is that the percentage of germination increased proportionally to the duration of the exposure of the pollen in the atmosphere after the dehiscing of the anther, though this relation differs according to the kinds of plant. The percentage of bursting, on the contrary, decreased in proportion to the duration of exposure.

These facts lead us to consider that the degree of dryness plays an important rôle in germination. It is obvious that the velocity of the loss of moisture from pollen grains must be variable according to the humidity of the air in which they are exposed. KNOWLTON (1922) has recognized this fact in his experiments on the longevity of corn pollen (see his tables 26 and 27). Whether any physiological change in the pollen grains in a certain period, as the so-called "after ripening", occurs to secure better germination or whether any physico-chemical change of the cytoplasm is the factor necessary for the optimum condition for the germination of pollen, is the question in the present case.

The following experiments were undertaken to study the relation among the germination, the period of exposure, and the degree of dryness of the pollen. The loss of moisture of pollen grains can be determined exactly by weighing them, but this is accompanied by some disadvantages. ANDRONESCU (1915) stated that corn pollen had an average moisture content of about 57 per cent of its whole weight. KNOWLTON (1922) determined it as from 60 to 65 per cent. For the sake of convenience, we assume 60 per cent as the percentage of the moisture content of corn pollen. In KNOWLTON's experiment, the loss of water from pollen grain kept in a desiccator was 14% of the whole moisture content in two hours, that is 8.4% of the whole weight. There is, of course, a very small loss of moisture in a shorter time in air of greater humidity. Therefore, unless we take a large amount of pollen, we cannot find enough difference to be able to ignore the error of weighing. In the following experiments, a more convenient method is employed. Gramineae pollen grains generally have a smooth surface and show great turgidity at the time of dehiscence of the anther, but dry rapidly and become shrunken.

The quantitative amount of the loss by moisture from the pollen grains cannot be determined so accurately by the percentage of shrunken pollen as by weighing, though, shrinkage is a more delicate indication of drying and is available for a practical comparison of the rate of dryness of pollen.

### EXPERIMENT XL.

Pollen grains which were gathered in a thin layer on a clean glass plate were observed under the microscope every time just before the culture began, and the average percentage of shrunken pollen grains from many different fields on that plate was calculated. After the microscopical observation a small amount of pollen grains was taken from the plate for the culture. The relation between the dryness of the pollen and the rate of its germination and bursting was studied.

- A. Material: Pollen grains of *Hordeum sativum*.  
Medium: 1% agar with 0.9 mol sucrose, pH 6.7  
Results are shown in Table LVIII.
- B. Material: Pollen grains of *Secale cereale*.  
Culture medium: 1% agar with 1.1 mol sucrose, pH 6.4  
Results are shown in Table LIX.
- C. Material: Pollen grains of *Secale cereale* preserved in a desiccator.  
Culture medium: 1% agar with 1.15 mol sucrose, pH 6.5  
Results are shown in Table LX.
- D. Material: Pollen grains of *Zea Mays* "Catowber".  
Culture medium: 0.7% agar with 0.45 mol sucrose, pH 5.8  
Results are shown in Table LXI.
- E. Material: Pollen grains of *Zea Mays* ("Northwestern Dent" and "Mammoth Sweet").  
Culture medium: 1% agar with 0.3 mol sucrose, pH 7.0  
Results are shown in Table LXII.

TABLE LVIII.

## A. Two rows variety.

Time of exposure (in hours)	0.0	0.5	1.0
Percentage of shrunken pollen	0.0	70.0	95.0
Percentage of germination	3.2	13.3	22.5
Percentage of bursting	27.7	1.1	8.1

## B. Six rows variety.

Time of exposure (in hours)	0.0	0.5	1.0
Percentage of shrunken pollen	0.0	50.0	95.0
Percentage of germination	6.7	7.9	24.4
Percentage of bursting	11.5	3.9	5.7

TABLE LIX. (See Fig. 14)

Time of exposure (in hours)	0.0	$\frac{1}{3}$	$\frac{2}{3}$	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.5
Percentage of shrunken pollen	0.0	2.0	6.0	15.0	25.0	35.0	45.0	50.0	70.0	85.0	100.0	100.0
Percentage of germination	22.9	20.5	38.2	38.7	39.5	55.7	45.2	61.0	78.8	70.8	64.4	54.8
Percentage of bursting	28.7	41.6	31.8	32.5	31.8	16.5	17.8	18.5	7.0	4.9	5.3	5.0

TABLE LX. (See Fig. 15).

Time of preservation (in hours)	0.0	0.5	1.0	1.5	2.0	2.5	3.0
Percentage of shrunken pollen	0.0	0.0	10.0	85.0	98.0	100.0	100.0
Percentage of germination	29.0	38.9	53.9	63.7	64.4	58.2	31.1
Percentage of bursting	13.4	17.4	27.4	11.1	12.8	5.5	4.1

TABLE LXI. (See Fig. 16)

Time of exposure (in hours)	0.0	0.5	1.0	1.5	2.0	2.5
Percentage of shrunken pollen	0.0	0.0	0.0	5.0	40.0	80.0
Percentage of germination	55.0	58.0	81.3	89.3	64.7	28.4
Percentage of bursting	12.5	2.3	4.1	0.0	0.0	0.0

TABLE LXII. (See Fig. 17)

Time of exposure		0.0	0.5	1.0	2.0
Percentage of shrunken pollen	A	0.0	0.0	0.0	4.0
	B	0.0	0.0	10.0	50.0
Percentage of germination	A	49.2	59.4	69.5	74.8
	B	11.5	43.6	50.1	49.8
Percentage of bursting	A	11.5	28.8	18.4	16.9
	B	1.3	13.5	5.8	6.1

Fig. 14. (Table LIX)

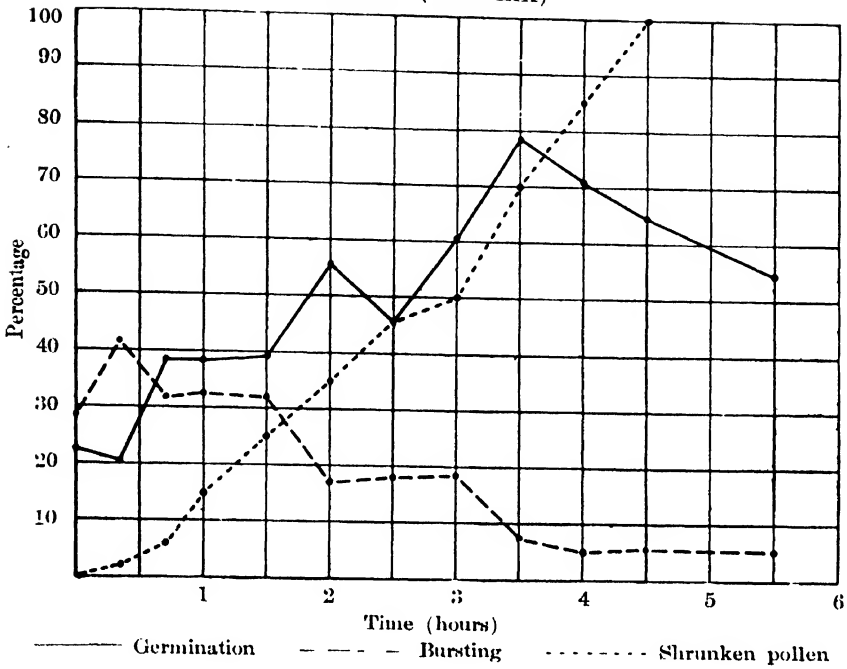


Fig. 15. (Table LX)

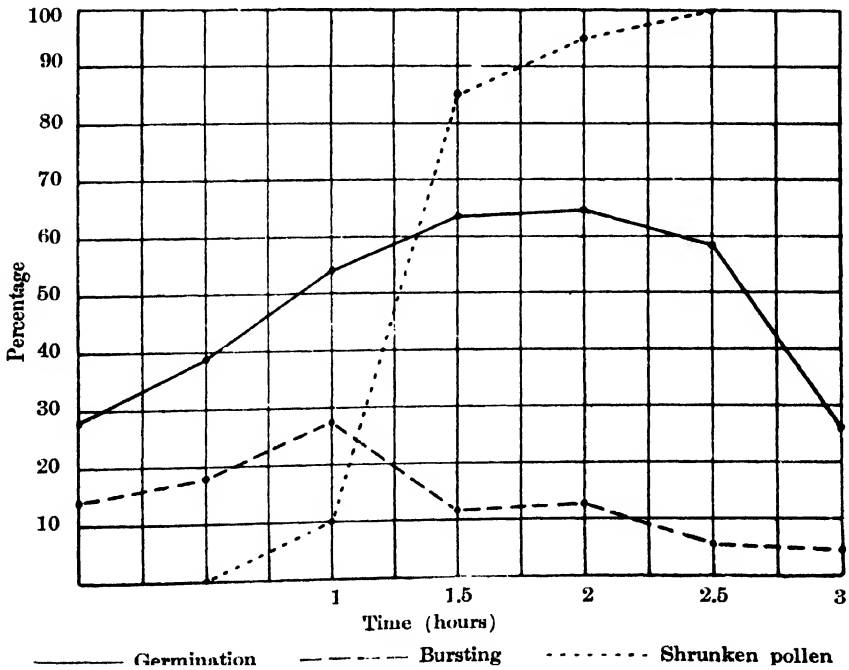




Fig. 16. (Table LXI)

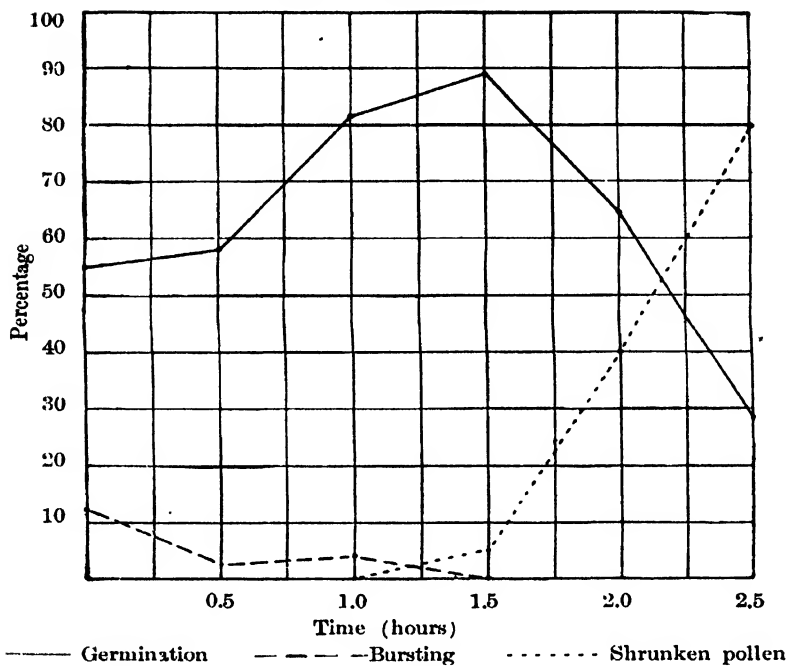
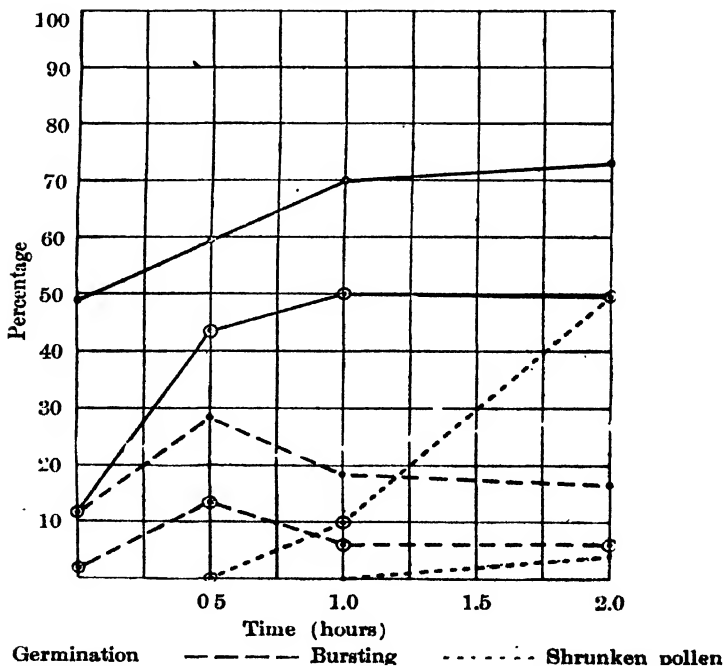


Fig. 17. (Table LXII)



The loss of the water content of pollen results in the decrease of turgidity first, and then the furrowing of the surface of the pollen follows. The percentage of the shrunken pollen, therefore, increases very slowly at the beginning but soon rapidly increases to 100%. The inclination of the curve of percentage of shrunken pollen is, of course, steeper in air of less humidity. In spite of the same environmental condition, the velocity of the drying of pollen is variable in different species and varieties. As seen in Table LXII, the percentage of shrunken pollen of "Northwestern Dent" is 4 in 2 hours, while in "Mammoth Sweet" it is 50. Independently of the velocity of drying, the best germination was obtained with the pollen grains of which 60-98% had shrunken, in rye pollen; in the case of corn pollen, with those of which 5-10% had shrunken, and in the barley pollen with those of which 95% had shrunken.

From these facts it is clear that a certain dryness for a certain kind of pollen is needed to secure the best germination. What can be proposed as an explanation of this fact?

The pollen grains which were stored for two days in the open air of the laboratory, as mentioned in the following table, showed better germination, after full recovery of their turgidity in a moist chamber, than that of the pollen used immediately after the dehiscence of the anther, or that of the pollen used before the complete recovery of their turgidity. The first pollen grains, which had dried once and recovered their turgidity, might be in a condition similar to the second only as to the water regulation of the culture medium, although the former might have a slightly less amount of reserve material than the latter. For this reason it can be assumed that the colloidal nature of the pollen membrane, probably the intine and the cytoplasmic layer, is changed by drying, and therefore becomes more suitable for artificial culture.

## EXPERIMENT XLI.

In this experiment, pollen grains of *Secale cereale*, stored for 2 days in the laboratory, were cultured at 20°C. on a culture medium of 1%

agar containing 1.1 mol sucrose, and the rate of germination and bursting was observed after 30 minutes' cultivation. Results are shown in Table LXIII.

TABLE LXIII.

	Fresh pollen	Stored pollen	
		Kept in a moist chamber for an hour before cultivation	Kept in a moist chamber for two hours before cultivation
Number of pollen grains	266	265	201
Percentage of germination	22.9	20.4	75.1
Percentage of bursting	28.9	3.0	2.5

### 3. Effects of other Conditions of the Culture Medium with a Consideration of the Dryness of the Pollen.

#### a. Influence of the Hydrogen-ion Concentration.

That the hydrogen-ion concentration of the culture medium plays an important rôle in the artificial germination of pollen has been already mentioned. The relation between the hydrogen-ion concentration of the culture medium and the dryness of the pollen is taken as the object of investigation in the following experiments.

### EXPERIMENT XLII.

In this experiment, pollen grains of *Secale cereale*, exposed in the air of the laboratory or stored in a desiccator, were cultured on culture media of various pH values containing 1% agar and 1.15 mol sucrose, and the rate of germination and bursting was observed. The regulation of the pH value of the culture medium was accomplished by the addition of hydrochloric acid. Results are shown in Table LXIV—LXVI.

TABLE LXIV. (See Fig. 18)

	pH value of medium	Time of exposure in the air (in hours)						
		0.0	0.5	1.0	1.5	2.0	2.5	3.0
Percentage of shrunken pollen		0.0	0.0	0.0	0.0	0.0	5.0	10.0
Percentage of germination	6.1	31.1	43.5	56.6	58.5	67.9	72.1	73.1
	6.7	29.9	31.7	39.0	45.6	—	51.4	57.5
Percentage of bursting	6.1	30.7	35.3	21.9	25.6	18.6	15.6	15.9
	6.7	48.5	52.2	43.5	30.0	—	30.0	19.1

“—” No observation.

Fig. 18. (Table LXIV)

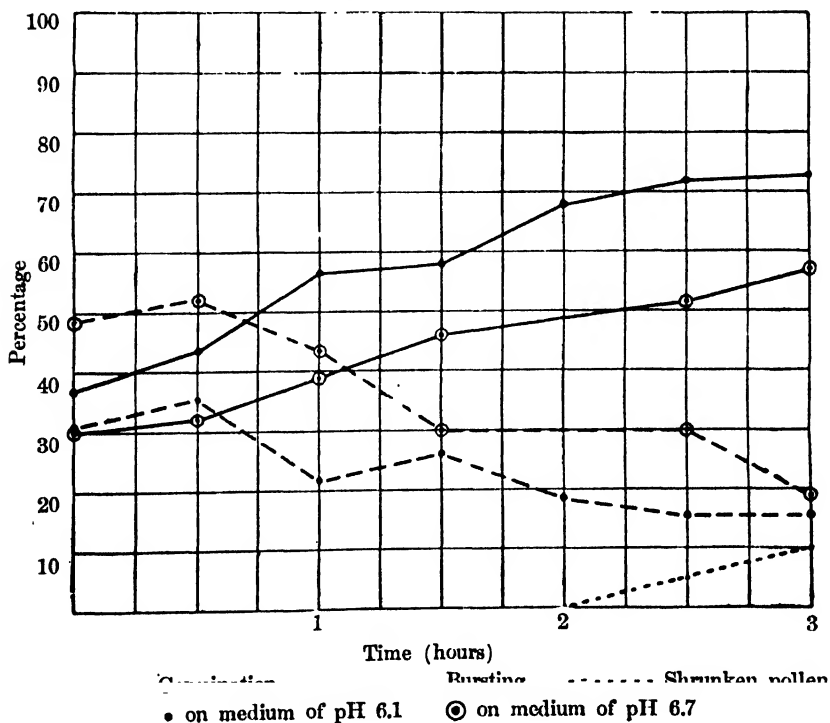


TABLE LXV. (See Fig. 19)

	pH value of medium	Time kept in desiccator (in hours)						
		0.0	0.5	1.0	1.5	2.0	2.5	3.0
Percentage of shrunk pollen		0	0	10	85	98	100	
Percentage of germination	6.1	20.0	38.9	53.9	63.7	65.0	58.2	31.1
	6.7	31.5	40.7	31.0	59.1	56.5	55.2	15.6
Percentage of bursting	6.1	13.4	17.4	27.4	11.1	23.8	5.5	4.1
	6.7	15.1	17.8	27.1	20.2	19.6	9.0	3.5

Fig. 19. (Table LXV)

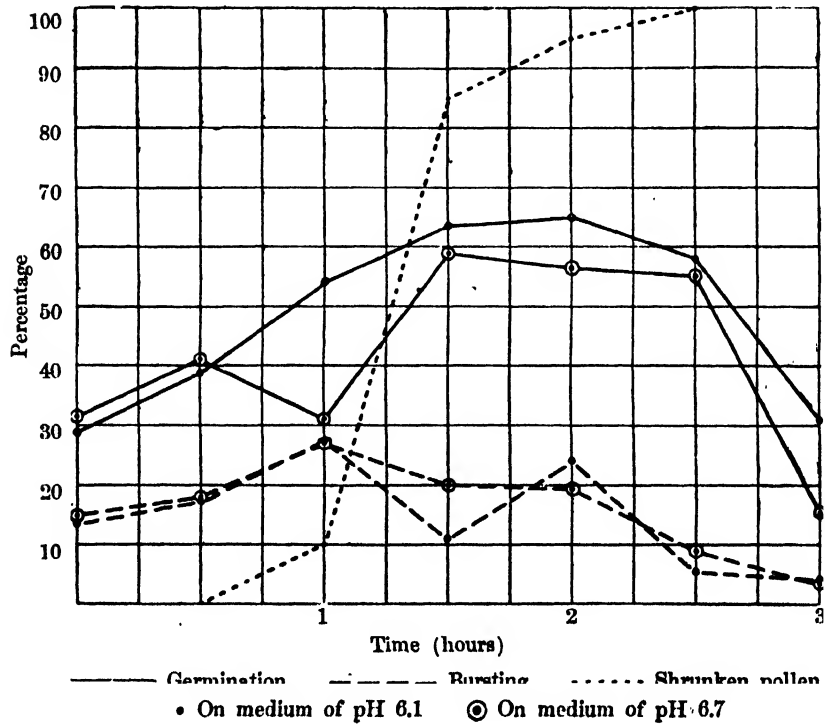
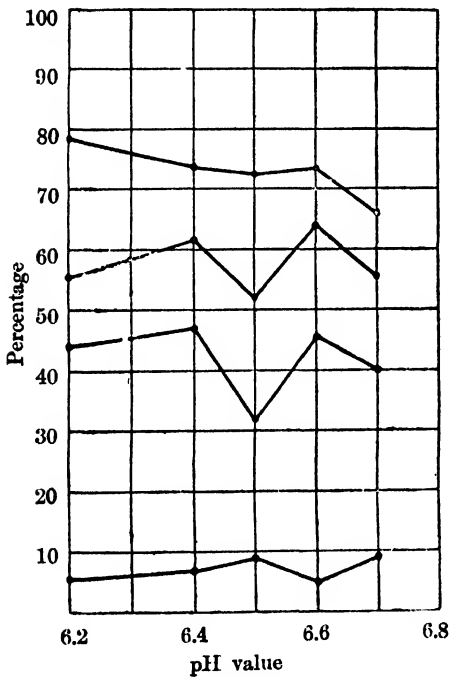


TABLE LXVI. (See Fig. 20, a and b)

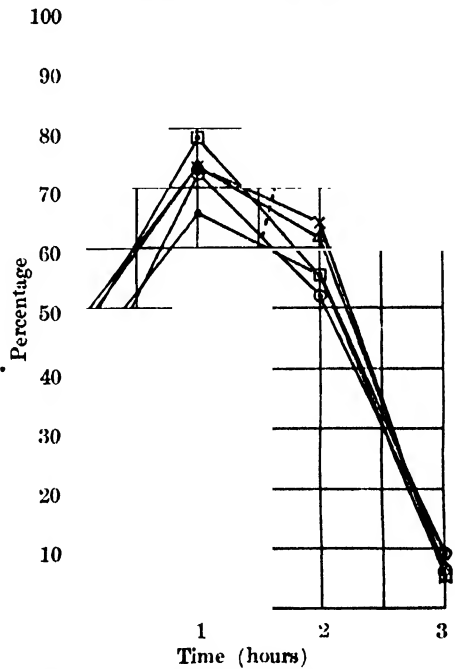
	pH value of medium	Time kept in a desiccator (in hours)			
		0	1	2	3
Percentage of shrunk pollen		0	20	100	100
Percentage of germination	6.7	40.0	65.8	55.5	9.3
	6.6	45.6	73.2	64.3	4.9
	6.5	31.9	72.3	51.9	9.1
	6.4	47.1	73.9	61.9	6.8
	6.2	43.7	78.4	55.5	5.5

Fig. 20 a. (Table LXVI)



- I. Fresh pollen  
 II. Pollen of one hour's exposure  
 III. Pollen of two hour's exposure  
 IV. Pollen of three hour's exposure

Fig. 20 b. (Table LXVI)



- Medium of pH 6.7 × Medium of pH 6.6  
 ⊙ Medium of pH 6.5 △ Medium of pH 6.4  
 □ Medium of pH 6.2  
 — Germination  
 - - - - - Shrunk pollen

When the pollen grains are cultured on culture media of various pH values, the germination curves effected by the dryness of the pollen are almost parallel (Tables LXIV, LXV, LXVI, and Figs. 18, 19, 20a, 20b). The most suitable dryness of the pollen for germination seems to be independent of the pH value of the culture medium. In the range of pH values between 6.0 and 7.0, which plain sugar medium commonly shows, the dryness of the pollen has a more important effect on the artificial germination than does the hydrogen-ion concentration of the culture medium. For instance, in Table LXVI the germination percentage of the pollen exposed in the air for one hour ranges from 65.8 to 78.4, while the best germination under other conditions is 64.3%.

#### b. Effect of Various Kinds of Sugar.

As to the special effect of sugar of various kinds upon the germination of pollen, there are MARTIN's experiments in the *Trifolium* species (1913) and the present author's on the relation to the polyploidy in the *Trifolium* species. (Tables XXXIII and XXXIV). The following experiments were made to observe the reaction of the sugars themselves to the germination of pollen.

### EXPERIMENT XLIII.

In this experiment, pollen grains of *Zea Mays* were cultured on a medium of 1% agar containing 0.3 mol sucrose or galactose, and the effect on the germination of the pollen was observed. Pollen grains exposed in the air of the laboratory were used here. Results are shown in Table LXVII.

TABLE LXVII.

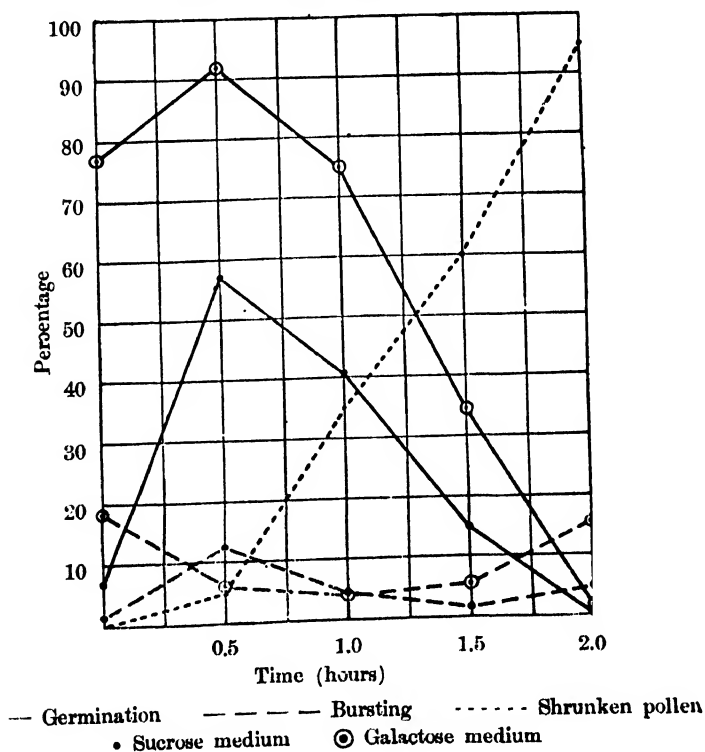
A. "Sweet Orange". (See Fig. 21)

	Kind of sugar	pH value of medium	Time of exposure in the air (in hours)				
			0.0	0.5	1.0	1.5	2.0
Percentage of shrunken pollen			0	5	35	60	95

TABLE LXVII. — (Continued)

	Kind of sugar	pH value of medium	Time of exposure in the air (in hours)				
			0.0	0.5	1.0	1.5	2.0
Percentage of germination	sucrose	7.0	6.9	57.2	40.7	14.9	0.0
	galactose	6.0	76.8	91.6	74.8	34.5	1.5
Percentage of bursting	sucrose	7.0	1.3	12.4	4.7	1.7	4.6
	galactose	6.0	18.5	6.3	4.2	6.5	15.4

Fig. 21. (Table LXVII, A)

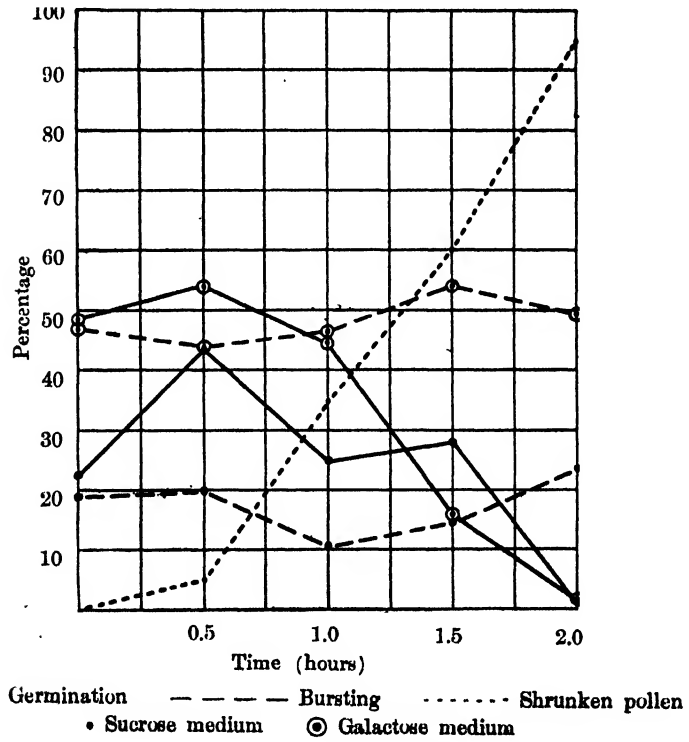




B. "Northwestern Dent". (See Fig. 22)

	Kind of sugar	pH value of medium	Time of exposure in the air (in hours)				
			0.0	0.5	1.0	1.5	2.0
Percentage of shrunken pollen			0	5	35	60	95
Percentage of germination	sucrose	7.0	19.3	43.4	25.0	28.2	1.3
	galactose	6.0	48.2	54.1	44.6	16.1	1.5
Percentage of bursting	sucrose	7.0	22.7	20.0	10.4	14.8	23.3
	galactose	6.0	47.8	43.6	46.4	54.2	49.7

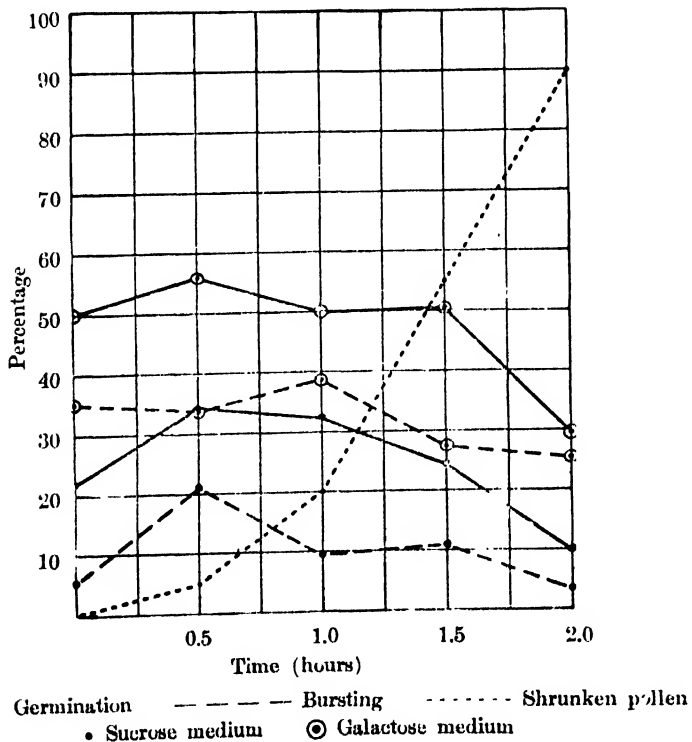
Fig. 22. (Table LXVII, B)



## C. "Large White Flint". (See Fig. 23)

	Kind of sugar	pH value of medium	Time of exposure in the air (in hours)				
			0.0	0.5	1.0	1.5	2.0
Percentage of shrunk pollen			0	5	20	55	90
Percentage of germination	sucrose	7.0	22.1	34.0	32.4	24.6	9.8
	galactose	6.0	50.0	56.1	50.0	50.5	28.3
Percentage of germination	sucrose	7.0	5.6	21.3	9.7	11.3	3.6
	galactose	6.0	34.6	33.8	38.7	27.8	25.8

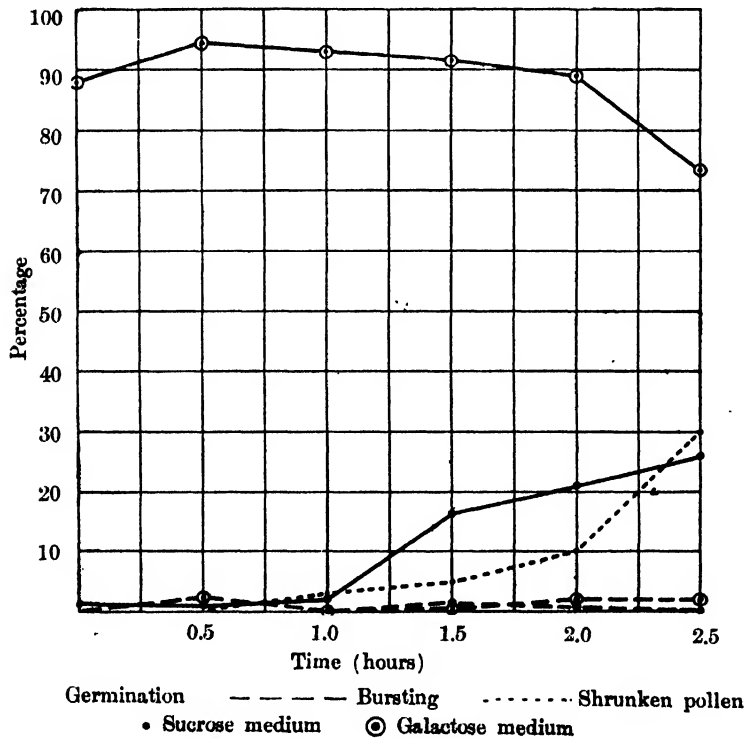
Fig. 23. (Table LXVII, C)



D. "Catowber". (See Fig. 24)

	Kind of sugar	pH value of medium	Time of exposure in the air (in hours)					
			0.0	0.5	1.0	1.5	2.0	2.5
Percentage of shrunken pollen			0	0	3	5	10	30
Percentage of germination	sucrose	7.0	1.3	0.5	2.0	16.6	20.8	26.4
	galactose	6.0	88.1	94.4	93.0	91.5	83.1	73.6
Percentage of bursting	sucrose	7.0	0.0	0.0	0.0	1.9	1.0	0.0
	galactose	6.0	0.0	2.5	0.0	0.6	2.2	2.1

Fig. 24. (Table LXVII, D)



## EXPERIMENT XLIV.

Pollen grains of *Zea Mays* "Catowber" were sown immediately after the dehiscence of the anther. A culture medium of 1% agar containing 0.3 mol sucrose, glucose, or galactose was used in this experiment, and the effect on the germination and the bursting of the pollen was compared. Results are shown in Table LXVIII.

TABLE LXVIII.

Kind of sugar	sucrose	galactose	glucose
pH value of medium	7.0	6.0	6.5
Percentage of germination	0.0	93.4	26.1
Percentage of bursting	0.0	5.6	0.5

From these experiments we can understand that the pollen grains of the varieties of corn used in the experiments show the best germination on the galactose medium, among the three kinds of sugar, and that the germination on glucose medium is better than that on sucrose medium. In the cases of "Sweet Orange" and "Catowber" such a special effect of sugar is especially marked. The pH values of the media are very different; that of the sucrose medium is 7.0, that of the glucose 6.5, and that of the galactose 6.0. Such a difference of the pH value of the culture medium has a certain effect on the germination and the bursting of pollen, as already mentioned in the foregoing chapter. In order to know the special effect of various sugars upon pollen germination, the relation between the pH value of the culture medium and the kinds of sugar in the germination of pollen must be studied. For this purpose the following experiments were made.

## EXPERIMENT XLV.

Pollen grains of *Zea Mays* were cultured on a 1% agar-medium containing 0.3 mol sucrose, glucose, or galactose. The pH values of the

media were regulated by the addition of hydrochloric acid. Pollen grains were sown immediately after the dehiscence of the anther. Results are shown in Table LXIX.

TABLE LXIX.

## A. "Black Starch".

Kind of sugar	Sucrose				Galactose	Glucose
pH value of medium	7.0	6.8	6.6	6.0	6.0	6.3
Percentage of germination	56.8	68.3	83.8	95.0	91.3	64.3
Percentage of bursting	6.5	5.8	6.8	3.1	4.5	1.4

## B. "White Ever Green".

Kind of sugar	Sucrose				Galactose	Glucose
pH value of medium	7.0	6.8	6.6	6.0	6.0	6.3
Percentage of germination	14.6	17.4	58.0	50.0	78.7	12.0
Percentage of bursting	13.2	10.9	28.4	34.9	13.3	55.4

## C. "Large Yellow Flint".

Kind of sugar	Sucrose				Galactose	Glucose
pH value of medium	7.0	6.8	6.6	6.0	6.0	6.1
Percentage of germination	3.7	9.0	19.7	30.4	25.0	31.0
Percentage of bursting	10.9	19.4	31.0	43.5	50.8	57.0

From these results it may be seen that when the pH value of the sucrose medium is diminished, the percentage of the germination increases in the pollen of every variety, and that when the pH value of the sucrose

medium is equal to that of the galactose medium, the percentage of germination in the former is equal to, or better than, that in the latter. In the case of glucose, the germination of pollen is comparatively worse than that of others, comparing the hydrogen-ion concentration of the medium. In the pollen grains of "White Ever Green", however, galactose shows a remarkably better effect and glucose a remarkably worse one than sucrose, though the pH value of the media are equal. From these facts it can be concluded that the germination of the pollen on a sugar medium is influenced more or less by the special nature of the sugar itself, but mainly by the pH value of the medium.

#### 4. *Germination of the Pollen of Oryza Sativa.*

*Oryza sativa* is the most important crop plant in Japan, and is the most popular and useful subject of plant breeding. Therefore investigation of the pollen, especially its artificial germination, is eagerly expected, but earlier results in this direction are very rare. Papers on this subject, as far as the writer is aware, have been published only by SASAKI (1919), and TABATA, KIKUCHI, and SASAKI (1929). SASAKI's result shows 7.1% germination and that of TABATA and others 64.5% in the upland-rice and 68.7% in paddy-rice. The latter results seem to be very satisfactory. The length of the pollen-tubes, however, varies from 1 to 32.4 $\mu$ , which are shorter than the diameter of the pollen grain. Therefore, it appears that pollen grains which produced a very much shorter pollen-tube than a half length of the diameter of the pollen grain are regarded as germinated ones in their data. Such a pollen-tube is called a nipple-like protrusion, and has not been counted in the rate of the germination in the present author's experiments. Measured by the standards applied in this paper, the percentage of germination in their data will diminish remarkably. From this result the artificial germination of *Oryza* pollen appears even yet as one of the most difficult cases in Gramineae pollen. The following experiments were made for the purpose of finding out more suitable conditions for the artificial germination of *Oryza* pollen, by using

the various methods which have been utilized in the foregoing experiments.

### EXPERIMENT XLVI.

The relation between artificial germination and the concentrations of agar, sugar, and hydrogen-ion was investigated in this experiment. Results are shown in Table LXX.

TABLE LXX..

No. of experiment	Conc. of agar (%)	Conc. of sugar (in mol)	pH value of medium	Number of pollen grains	Percentage of germ.	Percentage of burst.
1	1.0	0.3	7.0	67	18.0	55.2
	1.0	0.3	6.8	95	20.0	50.5
	1.0	0.3	6.4	83	27.0	34.9
2	1.0	0.33	5.8	248	84.7	—
3	1.0	0.33	7.0	230	30.4	17.8
	1.0	0.33	6.5	151	45.0	31.1
	1.0	0.33	5.9	163	29.4	25.8
	1.0	0.33	5.4	260	24.0	21.9
4	1.0	0.35	6.0	189	32.3	20.6
	1.0	0.35	6.0	118	33.0	31.4
5	1.0	0.35	6.0	396	26.5	17.2
	1.0	0.35	5.5	310	34.5	29.0
6	1.5	0.35	6.0	393	43.0	32.6
	1.5	0.35	5.8	420	34.0	31.6
7	1.5	0.40	5.9	238	43.8	23.1
8	2.0	0.35	6.2	213	24.4	56.3
	2.0	0.35	5.9	137	31.4	53.1
	2.0	0.35	5.6	104	42.3	32.7

Although the best germination in this table is 84.7%, the percentage of germination generally fluctuates from 20% to 40%. The medium which gave the best germination (84.7%) has not always shown such a high percentage of germination. Sometimes no germination was obtained on similar medium. In other cases it cannot be strictly determined what concentration of the hydrogen-ion in the medium is the most suitable, but about pH 5.9 seems to be the best condition. Agar medium of 5%, used by SASAKI (1919), has not been used in the present experiments due to the inconvenience of its preparation, but from the author's experience 1% agar is good enough for the purpose.

In order to investigate what change occurs in the character of the pollen during the blooming period, the germination of the pollen taken at four stages, ranging from the first instant of blooming to the instant of the dehiscence of the anther, was tested.

### EXPERIMENT LXXI.

Pollen grains of *Oryza sativa* were taken at different stages of blooming, and sown on a culture medium of 1.5% agar containing 0.35 mol sucrose and having pH 5.8. Results are shown in Table LXXI.

TABLE LXXI.

The first stage : The first instant of the opening of the glumes.

The second stage : The time of appearance of a half length of the anther out of glumes.

The third stage : The time of the filament of the stamen attaining its full length.

The fourth stage : The instant of the dehiscence of the anther.

Stage of blooming	1	2	3	4
Percentage of germination	34.0	13.7	33.5	30.4
Percentage of bursting	31.6	34.7	42.9	53.4



In the table the effects of each stage are seen to be practically equal, except that the germination of the second stage shows a relatively low percentage. Therefore, it may be concluded that the pollen does not change its character during the periods mentioned above.

That water which is treated with animal charcoal has a good effect on the germination of seeds or on the water culture of seedlings was ascertained in this laboratory. Such water was used for the germination of *Oryza* pollen (Table LXXII) but no especially good influence was observed.

### EXPERIMENT XLVIII.

In this experiment, pollen grains of *Oryza sativa* were cultured on a culture medium of 1% agar containing 0.35 mol sucrose. Water used for the preparation of the medium was treated with animal charcoal. The pH value of the medium was regulated to 5.6 by the addition of hydrochloric acid. Results are shown in Table LXXII.

TABLE LXXII.

No. of individual	1	2	3	4
Percentage of germination	43.1	34.8	18.8	38.3
Percentage of bursting	31.2	8.4	16.0	16.6

The following conditions, besides the above mentioned, were tested without any especially good result :

- a. Dryness of the pollen.
- b. Addition of a small amount of  $\text{CaCl}_2$  to the sugar-agar medium.
- c. Regulation of the water supply to the pollen grains by diffusion through a dry gelatine plate covering the sugar-agar medium.

After all, in spite of better results of artificial germination than that of the earlier workers, it is a matter of regret that it was not possible to get a method fully satisfactory for the artificial germination of *Oryza* pollen for practical purposes.

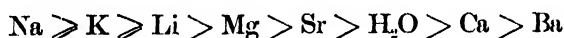
## SUMMARY.

1. The alkali substance which is dissolved out of a alkali glass effects the hydrogen-ion concentration of the solutions. Therefore glassware used for the artificial germination of pollen grain, especially the cover glass for a hanging-drop culture, should be made of non-alkaline glass. This precaution is the more necessary, the weaker the buffer action of the liquid.

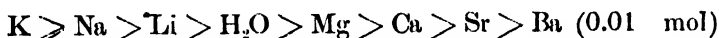
2. The sensitiveness of the pollen grain to the osmotic value of the outer solution depends on the elasticity of the pollen membranes and on the consistency of the cytoplasm. The hydrogen-ion and other cations, which act upon the colloidal nature of membrane and cytoplasm, are the important factors in the bursting and the germination of the pollen grain.

3. The series of cations arranged according to the rate of bursting of pollen grains resembles that of their penetrative power. They are as follows :

In the case of *Impatiens Balsamina* :

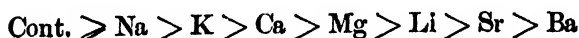


In the case of *Lysichiton camtschatense* :



4. The best condition for the germination of the pollen grain and its subsequent growth is a suitable balance between the consistence of the membranes and the cytoplasm, and the outward pressure in the pollen grain. When the suitable condition in the osmotic relation is secured, the series of the effect of cations on germination and growth resembles that in the bursting. In the case of *Hyacinthus orientalis* it is as follows :

For the germination of the pollen grain :



For the growth of the pollen-tube :

Cont.  $\succ$  Ca  $>$  Na  $>$  K  $>$  Mg  $>$  Sr  $>$  Li  $>$  Ba

The difference between these series is due to the rate of bursting of the pollen grains and the pollen-tubes.

5. Concerning the germination and the bursting of pollen grains, there is antagonism amongst cations, especially between Ca-ion and other cations.

6. Ba- and Sr-ion have such strong power to retard the bursting and the germination of pollen grain, that little or no germination and bursting is obtained in spite of the presence of other cations.

7. More or less antagonism can be obtained between alkali cations.

8. The influence of temperature on the growth of the pollen-tube differs with various species of plants, for example, the optimum temperature in *Thea japonica* and *Viola grypoceras* is 25°C. and in *Hyacinthus orientalis* 30°C.

— 9. The growth curve of the pollen-tube is, at least in an artificial culture medium, S-shape, resembling that of a mono-molecular autocatalytic reaction.

— 10. The relation between the rate of the growth of the pollen-tube and polyploidy is different between auto- and allopolyploidy. In the former case the rate of growth of the pollen-tube increases more or less proportionally to the chromosome number, but not in the latter case.

11. The reversed situation of the nuclei in the pollen-tube, namely the generative or the male nuclei followed by the tube nucleus, was observed in a pretty high percentage on the artificial culture media.

12. In the case of the pollen grain which develops two pollen-tubes, it is often observed that one of the pollen-tubes which included none of the nuclei could grow to about an equal length to that with the nuclei.

13. At least in the sugar concentrations of the culture media used in these experiments, the better the growth of the pollen-tube the quicker the division of generative nucleus in the pollen-tube takes place.

14. Modi of the formation of callose plug are classified into three types. A-type is a centripetal modus. It is composed of a thin plug with callose protrusions at its center on both sides. B-type is also a more or less centripetal modus. The beginning of the plug grows not only centripetally but also along the wall of the pollen-tube. The plug of the C-type grows from one side of the pollen-tube membrane to the other.

15. The distance from one plug to the following one is relatively regular in A-type and B-type. In the former, the intervals tend to increase towards the tip of the pollen-tube while they tend to decrease in the B-type. In the C-type the intervals show irregularity.

16. The secretion of the stigma favours the germination of pollen grains, and leads the pollen-tubes to the entrance of the stylar canal. After entering into the stylar canal, the pollen-tubes grow along the line of least resistance in the style to the ovary and are attracted to the micropyle by a certain chemotropic secretion out of the point.

17. The strength of the chemotropic effect of the stigma secretion and the sensitiveness of pollen-tubes to the stimulation are different in various species of plants.

18. In the artificial culture of Gramineae pollen, the dryness of the pollen grain is one of the most important factors, though the optimum dryness for germination of the pollen grain is different in various species of plants.

19. The dried pollen grain, after recovering its turgidity in a moist chamber, can germinate better than the fresh.

— 20. Of course, the hydrogen-ion concentration of the culture medium plays a cardinal rôle in the artificial germination of the pollen grain, but within the range of the pH value which is usually presented by the sugar-agar medium, the dryness of the pollen grain is the more essential factor for its artificial germination.

— 21. The artificial germination of corn pollen on a sugar medium is influenced more or less by the special nature of the sugar itself, but mainly by the accompanying pH value of the medium.

22. For the artificial germination of rice pollen, the optimum pH value seems to be about 5.9, but other conditions could not be determined.

23. Relatively good results were secured in artificial germination in the present experiments.

### POSTSCRIPT

Reference should be made to VOM BERG's paper (Beiträge zur Kenntnis der Pollenphysiologie. *Planta* 9: 105—143, 1929) which was received after this manuscript was finished. He studied mainly the effects of the pH value of the culture solutions on the pollen germination and the growth of pollen-tubes, and found that various pH values of culture solutions resulted in two maximum germination curves in almost all kinds of pollen he used, having the minimum point at about pH. 5.0. He assumed from this fact that the minimum swelling of the plasma-colloid is at the iso-electric point.

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**EXPLANATION OF PLATES****PLATE I.**

- Fig. 1. Showing two pollen-tubes out of the same pollen grain which grow to about equal length, though one of them has nuclei and the other not. " " shows the tip of the pollen, and "N" nucleus.
- Fig. 2. Showing two pollen-tubes which grow out of the same pollen grain; one of them which has no nucleus can outgrow the other which includes both generative and vegetative nuclei. "G" shows pollen grain, " " the tip of the pollen-tube, and "N" nucleus.
- Fig. 3. Showing the beginning of A-type callose plug formation in the pollen-tube of *Thea japonica* var. *spontanea*.
- Fig. 4. Showing a complete callose plug of A-type in the pollen-tube of *Thea japonica* var. *spontanea*.

**PLATE II.**

- Fig. 5. Showing the beginning of B-type callose plug formation.
- Fig. 6. Showing clear growth ring in the callose plug growing in the pollen-tube of *Clivia nobilis*.
- Fig. 7. Showing the callose plug formation of C-type in the pollen-tube of *Clivia nobilis*.
- Fig. 8. Showing vacuoles "v" appearing at the portion near the pollen grain in the pollen-tube of *Lathyrus odoratus*.
- Fig. 9. Showing the nucleus "N" shut out from the apical portion of pollen-tube by a callose plug "P."
- Fig. 10. Showing a male nucleus "N" caught by a growing callose plug "P."
-



Pl. I

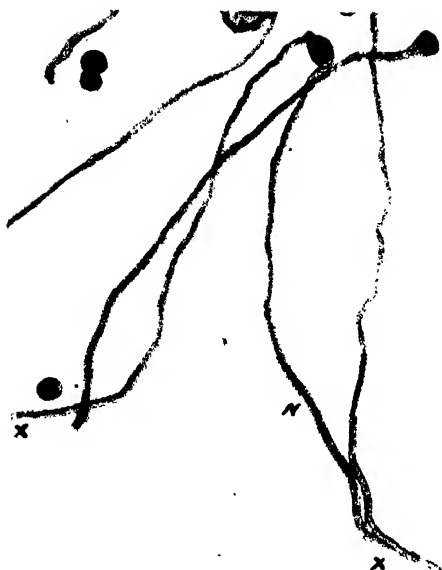


Fig. 1

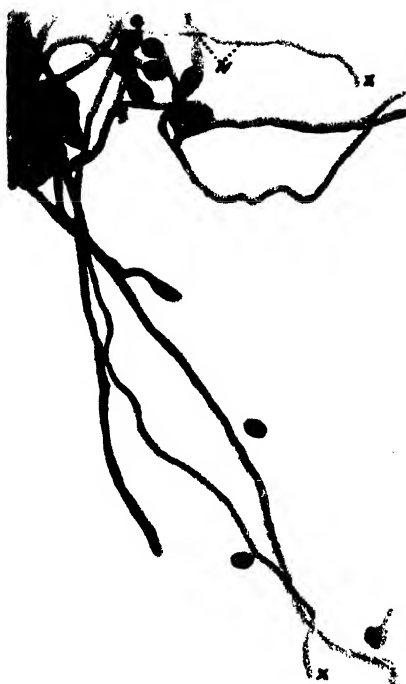


Fig. 2

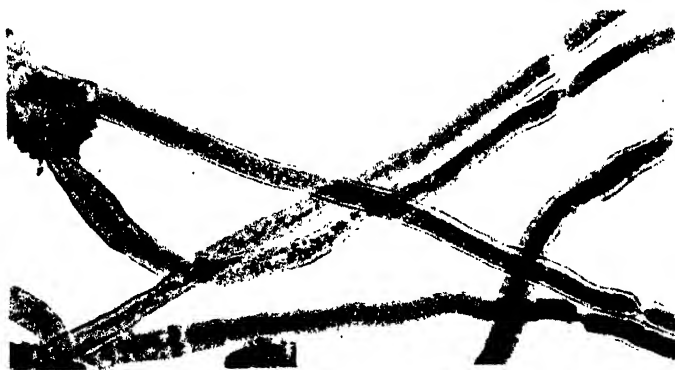


Fig. 3



Fig. 4



Pl. II



Fig. 5



Fig. 6



Fig. 7



Fig. 8



Fig. 9



Fig. 10



## ERRATA

Page	Line	Read	For
201	7	founded	founed
201	17	flat-topped	flattopped
202	20	teschenite	tessenite
202	24	generally in	generally
202	25	teschenite	tessenite
207	11	<i>filliaefolia</i>	<i>filliacfolia</i>
215	8	are almost restricted	are restricted
219	14	防 垣 洞	坊 垣 洞
219	20	防 垣 洞	坊 垣 洞
226	12	specimen	cpecimen
228	25	specimens	apecimens
230	26	alkalies	alkalis
230	31	alkalies	alkalis
236	10	chlorine	chlorite
242	7	Kyûshindô	Kyûshinbô
247	1	of the alkalies	the alkaline
247	19	extruded	extrured
250	6	of	of
251	2	龍 塘 浦	龍 塘 甫
252	Expl. of Fig. 2	The outcrops	the outcrops
257	21	components	componente
260	1	shown	sohwn
262	16	Mitsubishi	Mitsubish
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269	23	estimated	essimated
270	11	65.23	65.25
270	17	Na <sub>2</sub> O	Ma <sub>2</sub>





# ON THE STRATIGRAPHY OF THE SANSHIKYAKU DISTRICT NEAR TAIHOKU.

Keinosuke TAN.

With 3 Text-Figures, 2 Plates and a Geological Map.

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## I. INTRODUCTORY.

The geology of the Sanshikyaku (山子脚) district was studied some time ago by G. HOSOYA,<sup>1)</sup> a mining engineer of the Government-General of Taiwan, with special reference to the coal seams developed there.

1) G. HOSOYA:— "Report on the Coalfield of Sanshikyaku" (Japanese). Publication No. 236, Bureau of Productive Industries, Gov.-Gen. Taiwan, 1912,

For geologists this district is one of the most interesting and important in exhibiting the geological relations of the Neogene Tertiary of Taiwan. It is unique on account of the following points; (a) Most of the characteristic rock formations of the Neogene Tertiary of the island are well represented in a small area; (b) The area is close to the city of Taihoku, being about half an hour's distance by train; (c) An excellent topographical map which includes this area, on the scale of 1:25,000, has been issued by the Military Staff (Land Survey Department), whereas for the greater part of the island, reliable topographical maps are wanting at present.

The contents of this paper are mainly the results of the stratigraphical studies carried out by me during the summer of 1929, covering altogether about 40 days.<sup>2)</sup> As to farther investigations concerning the fossils, as well as the more detailed correlation of strata with those of the other districts, etc., another paper will be prepared in the future.

I take this occasion to acknowledge my indebtedness to Prof. I. HAYASAKA and Prof. T. ICHIMURA, under whose supervision the present work has been brought to this form.

To Messrs. S. HANZAWA and S. ENDÔ, both lecturers of the Tôhoku Imperial University, Sendai, I am indebted for the determination of fossil foraminifers and plants, respectively. Thanks are due to the authorities of the Fuel and Ore Testing Stations of the Government-General of Chôsen for the chemical analyses of the coal samples of this district.

## II. GEOGRAPHICAL.

(Refer to the following topographical maps on the scale of 1:25,000:  
Tôen (桃園), Nankan (南坎), Jurin (樹林), Taihoku-Seibu (臺北西部),

What I describe here as the Sanshikyaku district is a small hill situated about 14 km. SW of Taihoku, which occupies an area of about 40 sq. km.

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2) A short preliminary report was published in the Transaction No. 105 (vol. XIX.), Nat. Hist. Soc. Taiwan. 1929.

In the central part of the area there runs a watershed ridge, of which the highest peak is more than 400 m. above sea level, trending from NE to SW; the north-western side of the ridge descends to the extensive gravel-covered tableland, and the south-eastern side goes down abruptly to the level of the Taihoku basin.

Though a number of young valleys develop on the sides of the ridge, they are all small in scale. However, the hill is bounded on two sides by more or less conspicuous rivers. The one runs along the northern border of the area, flowing toward the east, following the fault line separating the gravel bed in the north from the Tertiary formation in the south: this river has no definite name. The other, called Toshikō (兎子坑), on the western border, flows along a certain tectonic line, its upper course and a tributary being almost at right angles to the main stream: this presumably being due to the phenomenon of beheading.

The topography of the district, as a whole, is very young, but its valleys with wide mouths and rugged ridges make a striking contrast to the extensive, flattopped, gravel-covered tableland, incised by deep, narrow gorges, seen on the north (Pl. I. Fig. 1, Fig. 2).

### III. GEOLOGICAL.

#### A. General Aspects of the Geology.

The sedimentary formation consists of beds of sandstones, shales, alternation of sandstone and shales, with subordinate calc-tuff beds.

These rocks make an anticlinal structure with the axis running from NE to SW, and pitching up in the NE. The anticline as a whole is overturned toward NW, as can be judged from the trend of strata in the eastern and northern parts of the hill (see profiles and geological map).

The strike of the strata coincide roughly with the direction of the anticlinal axis; the anticlinal structure being well observed at Taikochō\*.

\*At the east of the house of Gan Jam, 200, Taikochō, Shakōchō, Toshikō, Kizan-shō. (龜山  
庄兎子坑宇社後地大湖頂二百番地磐岩)

The inclination of the strata gets steeper from the ridge toward the bordering parts of the hill, that is,  $5^{\circ}$ – $30^{\circ}$  at the ridge and  $50^{\circ}$ – $70^{\circ}$  at the margin.

The succession of the rock formations of the Sanshikyaku district is divided into three, as follows (from above);

Tableland Gravel Bed. (A)

Kizan (龜山) Group. (B)

Sanshikyaku (山子脚) Group. (C)

Of these, the Sanshikyaku Group, the main body of the anticlinal structure, is subdivided into the following four Beds.

Sanshikyaku Group	{	Upper Marine-Fossil Beds.	(IV)
		Upper Coal-Bearing Beds.	(III)
		Lower Marine-Fossil Beds.	(II)
		Lower Coal-Bearing Beds.	(I)

There is no stratigraphical break between any two of these Beds, while the Sanshikyaku Group comes into contact with the Kizan Group by a fault, and the latter is overlain unconformably by the Tableland Gravel Bed.

As to the igneous rocks, we may mention only the occurrence of some basic intrusives, namely, olivine basalt and tessenite, together with related pyroclastics.<sup>1)</sup> The olivine basalt, as will be explained in the following pages, occurs as sheets, its tufaceous and agglomeratic equivalents occasionally taking its place (as the agglomerate at the upper course of Toshikō), the latter generally associating with the *Lepidocyclina* Zone of the Low. Marine-Fossil Beds. The tessenite is found as dykes intruding into the Sanshikyaku Group.

A conical hill called Senzan (尖山) which rises on the Tableland Gravel Bed at about 1.5 km. to the SW of the Ôka (鶯歌) railway station is an attractive feature in this region. The hill is an erosion remnant of a basalt sheet (olivine basalt) now exposed overlying the platy sandstone of the Sanshikyaku Group, the dip at the foot of the hill being toward SW.

1) For igneous rocks, see the following paper:

ICHIMURA, T.:— "On the basalt and agglomerate, associating with the tuff beds in the Tertiary formation near the City of Taihoku" Trans. Nat. Hist. Soc. Formosa, Vol. XIX, No. 109. (in Japanese)

## B. Details of the Geology.

(A) *Sanshikyaku Group* (Possible total thickness 2200 m. +)

### (I) *Lower Coal-Bearing Beds.*

This is the lowest division of the total succession, and is exposed in the central part of the area. According to the difference of the lithic characters, it is subdivisible into two parts, the upper being the coal-bearing Proper and the lower, the white coarse-grained sandstone.

(i) *White Coarse-grained Sandstone.* Light grayish in colour, very thick and widely distributed in the coal fields of the northern part of the island. Thickness unknown.

(ii) *Coal-Bearing Proper.* 250 m. in thickness. It consists of an alternation of beds of sandstone and shale. The sandstone is characterized by ripple marks and ferruginous, slag-like, reddish-brown incrustations.

The coal seams are variable in number, but there is only one workable seam which is about 30 to 50 cm. thick. It is a brittle, bituminous coal with a strong luster. No apparent difference exists between this and the coal of the Upper Coal-Bearing Beds. It has been believed that coals of the various beds of northern Taiwan can be distinguished according to the difference in their caking power. But such a difference is not so evident as expected, at least, in the coals of the Sanshikyaku district, as will be seen in the table of their chemical analyses which follows (Table I).

TABLE I.

## Analyses of Specimens of Various Coal Seams.

Samples	Con-stituents	Moisture	Volatile Matter	Fixed Carbon	Ash	Sul-phur	Calorific Power	Caking or not Caking	Specific Gravity	Horizon of Coal-Seams	
										Up. Coal-Seam	Up. Coal-Bearing Beds
No. 1		4.83	32.66	58.88	3.65	1.57	7155.7	Caking	1.290	Low. Coal Seam	Up. Coal-Bearing Beds
No. 2		3.19	37.72	51.65	7.44	0.58	6908.7	"	1.324		
No. 3		3.56	44.64	48.25	3.55	2.80	7071.9	"	1.295		
No. 4		3.63	43.79	47.12	5.46	2.01	7099.8	"	1.282		
No. 5		4.03	40.53	53.32	2.12	1.42	7416.7	"	1.313		
No. 6		2.42	34.71	61.20	1.67	0.69	7691.6	"	1.285		
No. 7		3.88	31.08	57.59	7.45	0.85	6741.0	More or less caking	1.301	Low. Coal-Bearing Beds.	
No. 8		1.62	34.42	51.75	12.21	1.10	7165.1	Caking	1.303		
No. 9		3.85	31.31	63.06	1.78	0.85	7412.0	More or less caking	1.308		
No. 10		3.93	36.74	55.05	4.28	0.61	7165.1	Caking	1.310		

## LOCALITIES OF SAMPLES

No. 1, Shōfukō (津普坑)    No. 2, Pinaikō (坡内坑)    No. 3, Taikokō (大高坑)  
 No. 4, Reikyaku (横脚)    No. 5, Pinaikō (坡内坑)    No. 6, Taikochō, Syagokō  
 (社後坑大湖頂)    No. 7, Taiseikō (大青坑)    No. 8, Toshikō (鬼子坑上流右岸)  
 No. 9, Ōkōshi (横坑子)    No. 10, Toshikō (鬼子坑上流左岸)

(II) *Lower Marine-Fossil Beds.* (Possible total thickness 600 m. +)

This is composed of beds of sandstone, shale, alternation of sandstone and shale, with subordinate calc-tuff. Sandstone is micaceous, dark grayish in colour, and medium grained, and is sometimes either more or less tufaceous or arkosic. In this formation three characteristic fossil zones are recognized, namely, *Lepidocyclina* Zone, *Pecten* Zone, and *Ditrupea* Zone: they play the part of important key beds in the stratigraphical research of this district. They are briefly described as follows.

(i) *Lepidocyclina* Zone. Sandstone intercalating shale and calc-tuff, about 60–70 m. in thickness.

The calc-tuff which is fossil-bearing (*Lepidocyclina* and others) varies a great deal in its character, from a limestone at one extremity to a tuff at the other. In Sanshikyaku district, generally speaking, limestone predominates toward the west, and the tuff toward the east. The limestone exposed at the temple “Hakuunganji” (白雲巖寺) in Toshikô and the tuff in the valley of Pinaikô (坡內坑) are representative.

When fresh, this calc-tuff often shows cross-bedding, and when weathered and decomposed, it assumes a reddish brown colour on the exposed surface, which gives a clue to the recognition of its existence from a distance.

From this *Lepidocyclina* Zone, we have obtained *Lepidocyclina verbeeki* N. and H., *Miogyopsina millepunctata* YABE and HANZAWA, *Miogyopsina dehaartii* var. *formosensis* YABE and HANZAWA among foraminifers, and *Cellepora formosensis* N. and H. *Pecten* sp., *Echinoneus* sp., *Ditrupa* sp., *Lithothamnium* sp.

Typical fossil localities;

a) Pinaikô (坡內坑): near the railway station of Jurin (樹林), including two excellent, and probably the best known exposures. At one we find a tufaceous band of about 4 m. in thickness which is practically a heap of the shells of *Lepidocyclina*. (Pl. II., Fig. 2).

b) Taikôkô (大高坑)

c) Toshikô (塙子坑)

d) Batô (馬頭)

Fig. 1. shows the details of this zone as is observed at Pinaikô.

(ii) *Pecten* Zone. About 100 m. above the *Lepidocyclina* Zone, and about 150 m. below the *Ditrupa* Zone, we have a bed of fossiliferous sandstone, which is not more than 3–5 m. thick and contains *Pecten praesignis* YOK, in abundance. This is the *Pecten* Zone. This zone has not yet been traced so thoroughly as the other fossil zones, so that it can not be represented on the geological map. It is, however, certain that the zone is found not only in the Sanshikyaku district, but also in several other districts in North Taiwan.



The fossils obtained are *Pecten praesignis* YOK., *Cardium* sp., *Circe* sp., *Pecten (Vola)* sp., *Mastra* sp., *Cucullaea* sp., *Arca* sp., *Dosinia* sp.

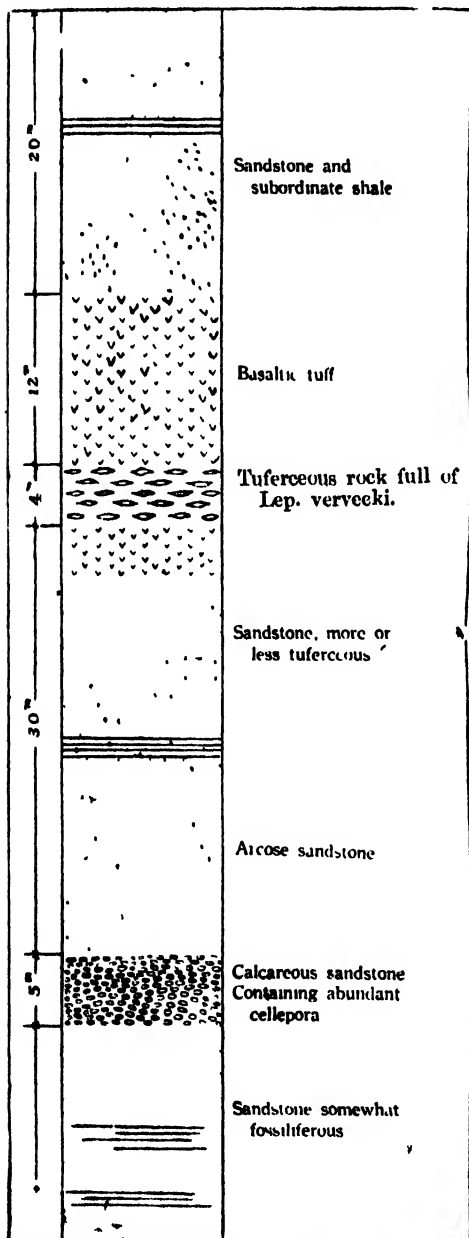


Fig. 1. *Lepidocyclina* zone exposed at Pinaikō

Typical fossil localities:

a) On the ridge to the north of Taikochō, Shagokō. (社後坑大湖頂)

b) On the ridge to the east of Shūshitōkō. (圳子頭坑)

c) In the upper-most course of the river of Toshikō. (鬼子坑)

(iii) *Ditrupa* Zone. About 250 m. above the *Lepidocyclina* Zone there comes the *Ditrupa* Zone. This is nearly 20 m. in thickness, and consists of more or less hard, calcareous sandstone which is rich in *Ditrupa* as well as in *Cellepora* cfr. *formosensis* N. and H., *Schizaster* sp. *a* and several molluscs.

The outcrops of the *Ditrupa* Zone generally form crests of hogback structure, (Pl. I, Fig. 2) owing to its hardness.

Typical fossil localities:

a) Ōkōshi (横坑子) (Pl. II., Fig. 3)

b) Sekkwaikō (石灰坑)

c) Pinaikō (坡内坑)

(III) *Upper Coal-Bearing Bed.* (Possible total thickness 500 m. +)

This consists mainly of alternating beds of sandstone and shale, and forms the cardinal parts of both of the north and south anticlinal wings, together with the overlying Up. Marine-Fossil Beds.

The lithic character much resembles that of the Low. Coal-Bearing Beds.

Two workable coal seams are in this formation, and another less conspicuous one is exposed at places. The workable seams are 30–70 cm. thick.

The following plant fossils have been found in the bed of platy sandstone underlying the lowest coal seam at Pinaikô.

1. *Ficus jilliacifolia* HEER.
2. *Ficus?* sp.
3. *Cassia* sp.
4. *Cinnamomum* cf. *C. vera* BERRY.
5. *Podogonium?* sp.

Fossil localities :

- a) Pinaikô. (坡内坑)
- b) Shôfukô. (樟普坑)

(IV) *Upper Marine-Fossil Beds.* (Possible total thickness 600 m. +)

This is composed of medium grained sandstone and shale, the sandstone being dark gray to brown in colour, sometimes green because of its glauconite content. When the sandstone is massive, it is considerably thick, otherwise it makes alternating beds with shales.

This is characterized by the following three fossil zones, of which the lowest one has been relatively well observed.

At Pinaikô, about 1 km. to the NW of the railway station of Jurin, and about 100 m. above the Upper Coal-Bearing Beds, there is exposed a fossiliferous rock, about 20m. thick, containing imperfect remains of molluscs. Within this zone there is sandstone band which is 30 cm. thick and is full of *Operculina bartschi* CUSH. Because of this foraminiferous band the lowest of these three zones is named the *Operculina bartschi* Zone (or Zone I). At Taikôkô (大高坑), about 150 m. higher

than this horizon, the *Operculina venosa* Zone (Zone II) lies. This is rich in *Operculina venosa* (F. and M.) and some molluscan fossils like *Ostrea*, *Pecten*, *Arca* etc., also occur. Next, Zone III comes, about 200 m. higher. This is represented by *Operculina venosa* (F. and M.), *Textularia* sp. *Pecten* sp. *Arca* sp., *Macoma* sp., *Lima* sp., *Solen* sp., *Retepora* sp., *Clypeaster* sp., aff. *C. virescens* Död., *Dentalium* sp.

Typical fossil localities :

*Operculina bartschi* Zone.

- a) Pinaikô (坡内坑)
- b) Gyâtokô (牛杜坑)
- c) At the North of Batô (馬頭)

*Operculina venosa* Zone.

- a) Taikôkô (大高坑)
- b) Pinaikô (坡内坑)

Zone III.

- a) At the railway cutting near the station of Sanshikyaku (山子脚)
- b) At the railway cutting about 600 m. east of the station of Ôka (鶯歌)

(B) *Kizan Group* (Thickness: unknown)

The rocks which constitute the foundation of the Tableland Gravel Bed, extending to the north and west of Sanshikyaku district, are, as a whole, called the Kizan Group, named after a village (represented on the map by the name of "Shinrokô" (新路坑), near which they are well exposed).

The Kizan Group, separated from the Sanshikyaku Group by the fault and overlain by the Tableland Gravel Bed unconformably, is composed of sandstone, shale, shaly sandstone, intercalated with thin coal seams (1-3 cm. thick) and marine-fossiliferous beds. They are bluish-gray in colour, are soft and are easily distinguished from other groups. This group, however, is exposed only in a limited area in this region and has not been studied in detail.

Near the boundary of the Sanshikyaku Group they strike from NE to SW, dipping 50°-60° toward SE, but as to the general trend of the strata nothing definite can be said at present.

**(C) Tableland Gravel Bed.**

It is evident that the Tableland Gravel Bed overlies the Kizan Group clino-unconformably. The latter Group is rather strongly disturbed, while the former lies horizontally everywhere above the latter. Moreover, in the Gravel Bed, blocks and pebbles derived from the Kizan Group are found very commonly, as for instance, at the road-cutting near the place called Juzangan (壽山巖).

The blocks in the gravel sometimes attain up to 70 cm. in diameter: they are either of older rocks which form the Backbone Range of the island, or of those of the Sanshikyaku and the Kizan Groups.

The Gravel Bed is covered by a red soil, the so-called "lateritic soil", not more than a few meters in thickness. The Gravel itself often appears to be cemented with a similar red matrix, though this appearance is limited to its upper portion, just below the red soil.

The height of the surface of the Tableland Gravel Bed differs in two sections of the region, viz., in the west and in the north-east. In the former section it is about 100 m. above sea-level: it is on this that the town of Tōen (桃園) stands. In the north-eastern section, the height is about 240 m. and extends close to the foot of Kwannonzan (觀音山), a dissected extinct volcano.

The thickness of the Gravel Bed varies a great deal, but it is estimated at 60 m. or so within this district.

**C. The Vertical Distribution of the More Important Fossils.**

The vertical distribution of the more important fossils in this district is summarized in the following table (Table II).

TABLE II.

## Vertical Distribution of More Important Fossils.

Fossils \ Fossil Zones	Lepidocyclina Zone	Pecten Zone	Ditrupa Zone	Operculina bartschi Zone (Zone I)	Operculina venosa Zone (Zone II)	Zone III
<i>Cyclodolys communis</i> MARTIN.....					X	
<i>Globigerina bulboides</i> D'ORB .....						X
<i>Globigerina b. var. triloba</i> REEVE.....						X
<i>Lepidocyclina taiwanensis</i> Y. et H .....	X					
<i>Lepidocyclina verbeeki</i> N. et H .....	X					
<i>Miogyssina mamillata</i> Y. et H .....	X					
<i>Miogyssina millepuncta</i> Y. et H .....	X		X			
<i>Miogyssina inflata</i> Y. et H .....	X		X	X		
<i>Miogyssina dehaartii</i> VLERK .....	X					
var. <i>formosensis</i> Y. et H.						
<i>Operculina bartschi</i> CUSH .....			X	X		
<i>Operculina venosa</i> (F. et M.) .....				X	X	X
<i>Biloculina</i> sp.....						X
<i>Carpenteria</i> sp. ....						X
<i>Lepidocyclina</i> sp. ....	X					
<i>Miogyssina</i> sp. ....	X		X		X	
<i>Textularia</i> sp.....						X
<i>Cellepora cf. formosensis</i> N. et H.....	X		X			
<i>Ditrupa</i> sp.....	X		X	X	X	
<i>Lithothamnium</i> sp.....	X					
<i>Clypeaster aff. virescens</i> DÖD .....						X
<i>Echinoneus</i> sp. ....	X					
<i>Schizaster</i> sp. a.....			X			
<i>Schizaster</i> sp. b.....				X		
<i>Pecten praesignis</i> YOKOYAMA .....		X				

## IV. CONCLUSION.

## A. Geological Columnar Section.

The above stated geological succession of this district is summarized in the following columnar section (Fig. 2).

## B. Stratigraphical Correlation with Other Regions of Taiwan.

The area studied by me is a rather limited one, but the stratigraphical relations, I believe, have been quite well established. In order to have the results rightly understood I will try to make a comparison of the rock succession of the Sanshikyaku district with those hitherto published of the other parts of the island.

First of all, the stratigraphical division proposed in 1928 by Y. ÔNOUE and others of the Imperial Geological Survey, Tokyo, for the Tertiary formation of Taiwan should be taken into account: this division has found general

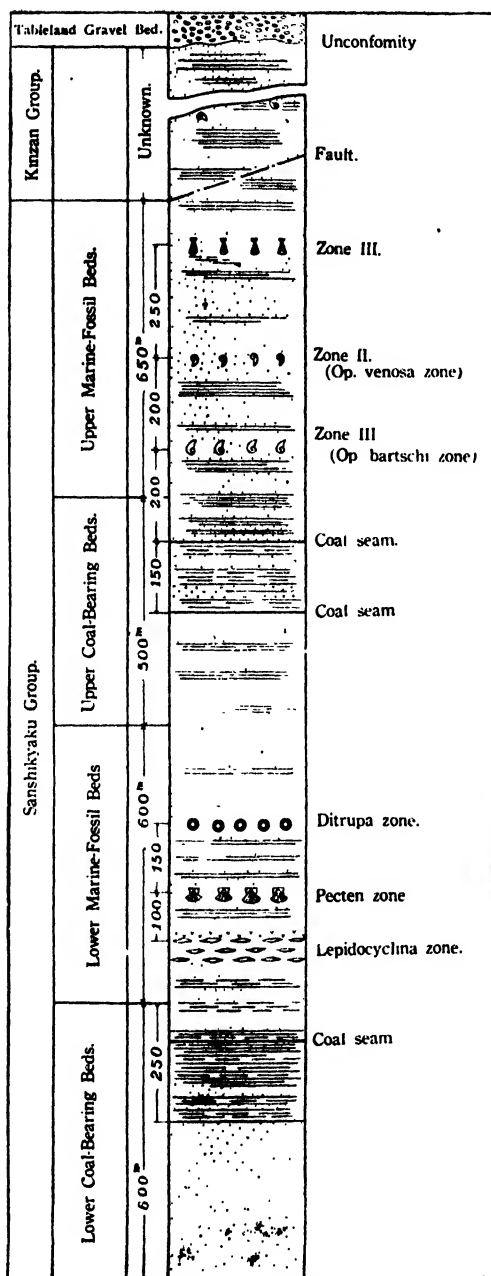


Fig. 2 Geological Columnar Section of the Sanshikyaku District

acceptance among the geologists in Taiwan.<sup>1)</sup> I am quite sure that the Sanshikyaku Group in my field corresponds to the greater part of the Up. Arisan Beds, and the Kizan Group, to a part of the Byōritsu, respectively.

More recently, Y. ICHIKAWA, geologist of the Government-General of Taiwan schemed a detailed stratigraphical division of the formations developed in the coal fields of the northern part of Taiwan. Although the details of his work has not yet been published, they are partly embodied in the three geological sheets recently published by the Government-General<sup>2)</sup>. They are also found in one of the recent works of YABE and HANZAWA on the fossil foraminifera of Taiwan<sup>3)</sup>, being quoted from ICHIKAWA's paper read by him, on the occasion of the 32th Annual Meeting (Sendai) of the Geological Society of Tokyo.

The following is the table of comparison between his and my divisions, in their essential features (Fig. III).

- 1) The stratigraphical divisions are

III. Pleistocene

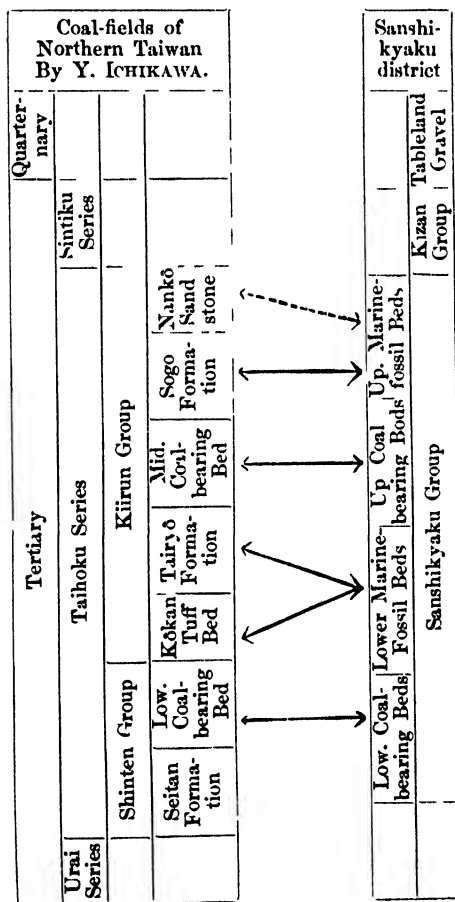
II. Tertiary { Shokkōzan Beds  
 { Arisan Beds { Upper Arisan Beds  
 { Lower Arisan Beds

I. Pre-Tertiary.

- 2) Tōen (桃園); Tikutō (竹東); Taihoku (臺北).

- 3) Sci. Rep. Tōhoku Imp. Univ. 2nd. ser. vol. XIV., No. 1. Of their stratigraphical divisions, the Kisan Bed. includes the Sanshikyaku Group of the region under consideration.

Fig. III.  
Stratigraphical Comparison





**Post-Script:**—While this paper was in press I happened to hear about the gas seeps at two places in the upper course of the Toshikō, the chemical constituent of the gas being as follows.<sup>1)</sup>

Date of Sampling	20th., Aug., 1931.
Date of Analysis	21st., Aug., 1931.
Average Atmos. Pres. and Temp. during the Analysis	756. 4 mm.; 30°C
CO <sub>2</sub>	5.30 %
Cm Hn	—
O <sub>2</sub>	0.22 %
CO	0.27 %
CH <sub>4</sub>	83.55 %
H <sub>2</sub>	0.16 %
N <sub>2</sub>	10.50 %
B. T. U/ft <sup>3</sup> , 60°F. 30" wet	839.4

(Analysed by the Government Central Research Institute, Taiwan; not published.)

1) For these informations I am indebted to Messrs. YAMASHITA and T. KONO.

# **PLATE I.**

## **Explanation of Plate I.**

Fig. 1. A north-east view from near Batô on the water-shed ridge of the Sanshi-kyaku district showing the flat topography of the Tableland gravel, with Kannonzan, an extinct and ruined volcano, rising above the level of the table-land. The table land is rather sharply dissected by valleys as is shown in the front.

Fig. 2. An example of the hogback structure characteristic of the Tertiary regions of northern as well as southern parts of Taiwan. The picture represents a part of the southern slope in the valley of Taikôkô, showing a ridge of sandstone bed interbedded with much less resistant shale beds.



1

2





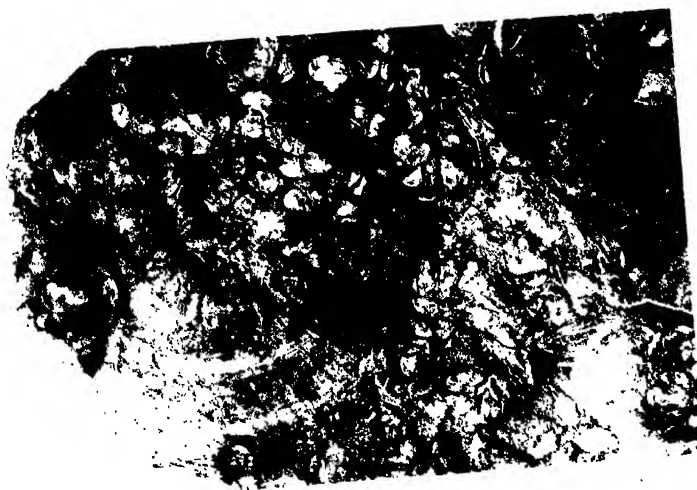
## PLATE II.

## Explanation of Plate II.

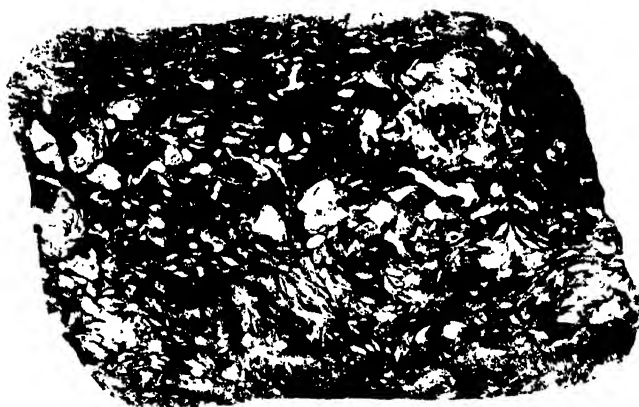
Fig. 1. A hand specimen of sandstone with *Operculina bartschi*, belonging to the Upper Marine-Fossil Beds. The specimen occurred at Gyûtokô. Note the mode of occurrence of the foraminifer.

Fig. 2. A hand specimen of *Lepidocyclina* rock from Pinaikô, showing the very abundant occurrence of the foraminifer. This rock belongs to the Lower Marine-Fossil Beds. In the neighbourhood of Pinaikô, *L. verbeeki* is naturally washed out in profusion.

Fig. 3. A typical example of the occurrence of *Ditrupa*, the specimen having occurred at Okôshi. This is a calcareous sandstone occupying a position about 220 m. above the *Lepidocyclina* zone referred to above.



1



2



3





# ALKALINE ROCKS FROM THE FRONTIER REGION NEAR KAINEI, CHOSEN (KOREA).

By

Takeshi ICHIMURA.

With 2 Text-Figures and 13 Plates

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## INTRODUCTION.

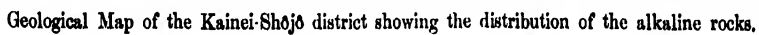
It is noteworthy that many kinds of alkaline rocks have been discovered in Korea during the last decade. As far as is known at present the occurrences are restricted to the northeastern part of the peninsula, the principal localities being to the north and south of Kankyō-dō where Pre-Miocene has mostly been assigned to these rocks.

In the frontier region, analcite-bearing rocks are abundant in the Tertiary coal fields which extend from Kainei (會寧) up to Onjō (穩城) and Keigen (慶源), particularly in the Kainei-Shōjō (鐘城) district, where they were intruded into the Tertiary rocks as sills, dikes, and laccoliths. The most common of these is trachydolerite which is often associated with such minor differentiation products as alkaline syenite, alkaline gabbro, olivine trachybasalt, basanite, and subalkaline rocks. Some of these rocks also occur in the Tertiary area of Manchuria which is separated from the Kainei district by the Tōman-kō (豆滿江).

The writer has also studied a similar type of trachydolerite in the specimens given him by Mr. SHIGA, who collected them in the Tertiary areas of Ku Lung Shan (Wang Ching Hsien)<sup>1)</sup>, Hei Shih Ling (Armur Hsien)<sup>2)</sup>, and on the summit of Yen Chi Ling (Yen Chi Hsien)<sup>3)</sup> in North Manchuria. The trachydolerite commonly found in the Kainei district frequently shows similarity in many points to the teschenite from the Taihoku district of Taiwan (Formosa). In the Taihoku district teschenite forms sills between the Miocene sediments. During a recent trip through San Luis Obispo and Ventura Counties of California, the writer also had a good opportunity to see some large sills and laccoliths of analcite-bearing diabase<sup>4)</sup> which is more or less similar to the trachydolerite from Korea, particularly in the association of minute dikes or masses of alkaline syenite. The rocks are now being investigated by Dr. N. L. TALIAFERRO<sup>5)</sup> of the University of California.

In the frontier region of Chōsen (Korea) analcite-bearing rocks are restricted to the Tertiary area. Enormous faulting occurred after their intrusions, but no evidence was found of an earlier faulting which brought up the alkaline magma from a depth, as supposed by Mr. YAMANARI<sup>6)</sup> in his paper on the alkaline rock province surrounding the

- 1) 吉林省汪清縣、百草溝廣義山    2) 吉林省額穆縣黑石嶺    3) 吉林省延吉縣延吉嶺上
- 4) H. W. FAIRBANKS:—On Analcite Diabase from San Luis Obispo County, California. Univ. Cal. Publ. Geol., Vol. 1 (1895), pp. 273-300.
- 5) N. L. TALIAFERRO:—Analcite Diabase and Related Rocks in California (Abstracts). Geol. Soc. Amer. Program (Cordilleran section), 1930, pp. 9-10.
- 6) F. YAMANARI:—Cenozoic Crustal Movements and Volcanic Activities of the Alkaline Rocks Region surrounding Japan Sea (in Japanese). Jour. Geol. Soc. Tokyo, Vol. XL (1928), No. 474, pp. 471-477.





Japan Sea. And, in addition, no evidence was found of a relation between the occurrence of alkaline rocks and limestone as contended by Dr. DALY.<sup>1)</sup>

The writer<sup>2)</sup> has already published preliminary notes on the occurrence and petrological character of these rocks, soon after the completion of the field work on the frontier coal fields which was done under the Government of Chōsen. Some typical specimens were sent to Tōhoku Imperial University of Sendai, where chemical studies were made by Prof. Kōzu and Prof. SETO. The results were presented by Prof. Kōzu<sup>3)</sup> to the Fourth Pacific Science Congress. The present paper is the result of a further study of these alkaline rocks made by the writer at Taihoku Imperial University and the University of California.

The writer is much indebted to Prof. Kōzu and Prof. K. SETO, as well as to Mr. T. Kōno, for the chemical analyses of the specimens. I wish to thank also Prof. N. L. TALIAFERRO, of the University of California, who has offered many helpful suggestions. In addition, the writer's thanks are due to Mr. S. G. CLARK, of Berkeley, for his critical reading of the preliminary manuscript. The manuscripts of this and the next articles, having been sent from abroad to Prof. I. HAYASAKA for publication, must necessarily trouble him in every way in being printed: the writer is deeply indebted to him.

## GENERAL REMARKS.

In the frontier region the area which is occupied by the Tertiary sediments is hilly and poorly forested, making a distinct topographical

- 1) R. A. DALY:—*Igneous Rocks and Their Origin*, 1914, p. 410.
- 2) T. ICHIMURA:—*On Basalts in the Kainei District, N. Kankyō-dō, Chōsen* (in Japanese). *Jour. Geol. Soc. Tōkyō*, Vol. XXX (1922), pp. 413-428.  
T. ICHIMURA:—*Preliminary Notes on the Mode of Occurrence on the Alkaline Syenite in the Kainei District, Korea*. *Jap. Jour. Geol. and Geogr.*, Vol. III (1924), No. 3-4, pp. 101-103.
- 3) S. Kōzu and K. SETO:—*The Chemical and Microscopical Studies of Some Korean Rocks*, Abstract of Paper from the Fourth Pacific Science Congress in Java (1929).

contrast to the surrounding mountains of granite and Palaeozoic metamorphics. This monotonous area, however, is frequently interrupted by peculiar reliefs due to the intrusion of analcite-bearing rocks which are particularly common in the Kainei-Shōjō district (Pl. I). These intrusions have sometimes been carved by erosion to characteristic mesas, such as Sanjō-san (山城山), Nyūnō-hō (入應峰), and Gokokujōshi (五國城趾), and sometimes to typically dome-shaped masses, while others have more or less complicated forms, as shown by Kacchū-hō (甲冑峰), Sho-hō (諸峰), Shōchōdōsoku-san (小長洞側山), Shōhō-san (小豊山), Seigi-hō (西儀峯), and Mafun-san (馬墳山), which often rise over 700 meters above sea-level.

The analcite-bearing rocks found here are mostly trachydolerite, olivine trachybasalt, and basanite, and are sometimes associated with alkaline syenite, alkaline gabbro, and glassy basalt. The alkaline syenite forms small dikes and oval-shaped masses in the dikes and laccoliths of trachydolerite and is not widely distributed. Most of the other rocks associated with trachydolerite grade into it within the same mass. The intrusions occur as sills, laccoliths, or dikes. The laccoliths often become thin at their borders, resembling sills. Both sills and laccoliths are occasionally seen to be connected with dikes descending from their bases. These dikes are considered to be the vents through which the magma rose.

At the contact with the intrusions, the sediments show a low grade of metamorphism, giving changes in color, dense flinty-like hornfels, and the alteration of lignite to natural coke, anthracite, and coking coal.

### TRACHYDOLERITE.

(1) **Distribution and Mode of Intrusion:**—As will be understood from the following description of individual occurrences, trachydolerite is only intruded into the Tertiary rocks. In these rocks it shows a wide lateral and vertical range, occurring as dikes, sills, and laccoliths. The disturbance of the Tertiary rock is partly due to these intrusions, but is mainly due to the great diastrophism which came at a later date.

Sometimes trachydolerite is noticeably differentiated from the contact zone toward the center of the body: this being more noticeable in the larger bodies. In many cases columnar or tabular jointing was formed during the cooling of the sill, the two types often occurring together. The best examples are to be seen at Gokokujōshi, Katō-dō (下塔洞 Pl. IV, b), Endaigai (煙臺外), Shinkō-dō (新興洞), etc. At these localities the columns have a square or pentagonal section, one meter or more in diameter. They are often crossed by tabular cracks, six to twenty centimeters apart. Such jointing is usually very distinct along the contact. Trachydolerite weathers very easily, beginning with zeolitization and the formation of onion structures and then disintegrating into loose, sandy materials.

One of the most extensive exposures is found along the valley near Bōtan-dō (坊坦洞), where it occurs in the middle coal-bearing beds and is separated from granite by a thin layer of sediments. The trachydolerite forms an irregular laccolith which has a maximum thickness of about 200 meters. It is partly covered by patches of shale and sandstone which are erosional remnants of the upper contact and of xenoliths. The eastern side of this laccolith is cut by a NE-SW fault which has brought it into contact with the granite of Bōtan-rei (坊坦嶺).

Along the Saisen-dō (細川洞) valley many dikes and laccoliths, at the hill of Shōhaku-dō (松柏洞), have been intruded into the Tertiary sediments.

In the area between Kōé (行營) and Kainei the relations are more complicated. Here many laccoliths and sills of variable dimensions have been intruded into the interbedded sandstone, shale, and conglomerate. It has a very irregular distribution on the hummocky hills of Kyūshin-dō (弓心洞) and Shaotsu-dō (沙乙洞) where it forms sills and laccoliths in the middle coal bearing horizon or in the overlying shale. The trachydolerite is more conspicuously exposed on both sides of the Hachiotsu (八乙) River. The characteristic reliefs, as shown by Shōchō-dōsoku-san, Nyūnō-hō, Mafun-san, and Seigi-hō, are made up of laccoliths, while those of Sanjō-san, and Shōhō-san are sills (Pl. II). Most of them



are surrounded by talus which often obscures the contact of the intrusives with the Tertiary sediments. Among them the sill of Sanjō-san abruptly projects out of the gently sloping hill which is largely covered by talus. The maximum thickness is approximately 150 m. and the highest point is 740.5 m. above sea-level. A very steep cliff occurs along the southern side. The sill appears to have been injected into the upper horizon of the Tertiary sediments, but the relations are almost entirely obscure because of the poor exposures of the sediments.

The body, which is poorly exposed near Gensan-dō (元山洞), was intruded into a still lower horizon. On the east it is terminated by a fault movement along which is caused the local exposure of granite at Kōju-hō (光珠峰). The sill extends southward across the Hachiotsu River and is probably connected with the sill of Shōhō-san.

The largest laccolith is that of Nyūnō-hō which covers 7.75 sq. km. and has a maximum thickness of approximately 500 m. This laccolith was intruded into SW-dipping beds of shale and sandstone. Immediately to the northwest another laccolith forms the Shōchōdōsoku-san. It is separated from the Nyūnō-hō laccolith by shale beds. It was probably intruded into a horizon a little higher than the middle coal-bearing beds. In the upper Shakatani (沙河谷) Valley the laccoliths of Seigi-hō and Mafun-san, associated with many sills and dikes, occur in well exposed sediments which belong to the middle or lower coal-bearing beds.

The isolated area of Tertiary sediments extending from Ryūkō-men (龍興面) to Ryūkei-men (龍溪面) is also an important locality for trachydolerite. The area was tilted up when the western side was uplifted along the major fault line which trends northeast to southwest, passing the eastern slope of Sanjō-san. Excellently exposed laccoliths and sills, among which are Kachū-hō and Shō-hō, cover the most of the northern half of this area. A most interesting example (Pl. III, a) can be seen along the valley extending south from Kyokusui-dō (極水洞). At this locality a laccolith is separated from an underlying sill by approximately 70m. of Tertiary shale.

The occurrence of trachydolerite is well known in the western part of the Kainei coal field where the Tertiary sediments extend across the Tôman-kô into the Chinese territory. On both sides of the river are many sills sometimes accompanied by dikes. The old castle called Gokokujôshi along the Tôman-kô (Pl. III, b and Pl. IV, a) rests on a characteristic sill, which is somewhat concave upward in the central part. Its thickness gradually increases toward the northern or western sides, where it reaches 60 m. Although the relations are somewhat obscured by talus, it was found to overlies the middle coal-bearing beds, just above conglomerate layers. The sill is thinly covered by the alternately bedded shale and sandstone. Another part of this sill, separated and tilted by a big fault along the Hootsu (甫乙) River, is found between Tôdô-toku (塔洞徳) and Zençihô-toku (前智方徳). This part is larger than that of Gokokujôshi and is traceable for a distance of 8 km. from north to south, being cut off to the north at Katôdô by a fault and thinning out to the south on the south side of the Hôgi coal mine. Its thickness reaches its maximum at Tôdô-toku where it is approximately 100 m., but that gradually decreases again toward the southeast, as shown by the diamond drill cores. This part of the sill was injected into the same horizon as that of Gokokujôshi and the sporadic distribution of minor isolated sills near Jôdô-dô (城東洞) and Shimosai-dô (下細洞) appears to indicate an original connection between them. The sill is probably genetically related to the large dike which is discontinuously exposed for about 7 km. to the opposite side of the frontier, past Kando-hô (甘土峰), Ôhō (鷹峰), and Endaihō (煙臺峰).

(2) **Megascopical and Microscopical Characters**:—The trachydolerite commonly found in this district is a holocrystalline and compact rock, with a black or dark grey color. The grain size is variable, particularly within the large bodies. In such cases it is commonly fine grained in the marginal facies with an increase in grain size toward the interior. Some of the trachydolerite is aphanitic, while other parts are porphyritic, often being characterized by a mottled appearance due to the minute aggregates of feldspars and ferro-magnesian minerals. It very commonly

shows a doleritic or ophitic texture under the microscope (Pl. VI, a, b and Pl. VII, a, b). The trachydolerite shows gradual transitions into differentiation products, such as alkaline gabbro, olivine trachybasalt, basanite, and glassy basalt.

The usual constituents are plagioclase, pyroxenes, olivine, biotite, magnetite, apatite, analcite, etc. However, there are local variations. Ferro-magnesian minerals are sometimes altered to secondary chlorite, serpentine, and nontronite. Among the primary constituents, plagioclase generally occurs in anhedral or subhedral lath-shaped crystals. The dominant varieties are andesine and labradorite which are always characterized by twinning after the carlsbad and albite laws. The phenocrystic crystals are sometimes 3.4 mm.  $\times$  0.76 mm. in size, but usually the length is from 0.08 mm. to 0.85 mm. When it is well zoned the outer zone is generally more acidic than the nucleous, and generally shows undulatory extinction. The index of refraction on 001 is measured as follows:—  $n_1=1.543$ ,  $n_2=1.550$  minimum and  $n_1=1.555$ ,  $n_2=1.561$  maximum. Hence this plagioclase seems to range between acidic andesine ( $Ab_{70} An_{30}$ ) and acidic labradorite ( $Ab_{40} An_{60}$ ). The mineral character is either positive or negative. The common inclusions are apatite, titaniferous augite, and magnetite, while rarely, e. g., in the specimens from Kacchô-hô and Nyûnô-hô, aegirine and aegirine-augite occur. They are generally associated with a more acidic variety which is oligoclase. This acidic plagioclase usually has an anhedral form., filling the interstices of the lath-shaped crystals of the other varieties. The oligoclase found is 0.75 mm.  $\times$  0.37 mm. in size and usually shows an indistinct and somewhat undulatory extinction. Carlsbad twinning is more common than the albite type, but neither is very common. The sign of the mineral is positive and the indices of refraction are  $n_1=1.539$  and  $n_2=1.543$  on 001. This corresponds to oligoclase, which is approximately  $Ab_{30} An_{70}$ . The extinction angle is very small. Some of the plagioclase crystals are partly sericitized and zeolitized by the hydrothermal action of the later igneous stages.

Olivine is an important mineral in this rock. In the porphyritic rock the phenocrysts are sometimes euhedral, but usually subhedral or anhedral. The irregular outline of crystal is partly due to magmatic corrosion. The largest phenocryst seen was 3.9 mm  $\times$  2.3 mm in size. The indices of refraction are  $N_p=1.657$  and  $N_m=1.689$ . Abundant magnetite grains, often associated with biotite flakes or apatite needles, occur as inclusions. Sometimes they are surrounded by the aggregates of magnetite, biotite, or augite, or, sometimes, by all three. Many cracks filled with serpentine or chlorite, together with minute magnetite grains, commonly cut the crystals. The olivine is easily decomposed by weathering, altering into serpentine, chlorite, and nontronite.

Among pyroxenes the most common is titaniferous augite. It is found abundantly as phenocryst and in the ground-mass, having either prismatic or granular form. Euhedral crystals are very rare. Minute grains together with magnetite, biotite, and analcite sometimes fill the interstices of the andesine or labradorite. Some of large phenocrysts include abundant laths of andesine or labradorite, giving a poikilitic structure, e. g., in specimens from the ridge between Yûsen-dô (遊仙洞) and Jôtô-dô and also Gokokujôshi. The largest crystal seen was 1.87 mm. in length and 0.425 mm. in width, while the common size is 0.08 mm. to 0.17 mm. in length. The usual pleochroism is;  $X$ =light purplish brown,  $Y$ =light yellowish brown,  $Z$ =light brownish purple.  $Z > X > Y$ . In some of the large crystal a zonal structure is seen. This indicates a change of titanium content during its crystallization. It is of interest also that titaniferous augite gradually passes into aegirine or aegirine-augite toward its margin. Hour-glass structure is rare. Twinning parallel to 100 is common and cleavage parallel to 110 is usually very distinct. The indices of refraction are  $N_g=1.7200$  and  $N_p=1.6865$ .  $Z \wedge c = 35^\circ - 40^\circ$ . The titaniferous augite rarely occurs as a radial aggregate. It often surrounds and includes olivine crystals. Magnetite and biotite are always associated with the augite, both occurring within the crystal and frequently as a reaction rim.

The occurrence of aegirine and aegirine-augite is not so common as titaniferous augite, being found only in the specimens from Shōseigi-hō (小西鐵峰), Kinsei-dō (金生洞), Nyūnō-hō, Kacchō-hō, Endaigai, Katō-dō, Shokyo-ri (所巨里). Aegirine is more common than aegirine-augite. Both minerals are found as minute crystals or as the peripheral facies of titaniferous augite. In certain cases it forms a reaction rim around titaniferous augite. Sometimes these three minerals occur together and in this case aegirine-augite is an intermediate zone in the transition from titaniferous augite to aegirine. Aegirine always forms the outer zone. The most conspicuous phenomenon is its frequent association with olivine, biotite and analcite. Aegirine and aegirine-augite often have a flaky or prismatic form, but are always anhedral. Aegirine commonly shows a very small extinction angle, viz.,  $X \wedge c = 3^\circ$  or smaller, while that of aegirine-augite is  $Z \wedge c = 60^\circ$  or thereabouts. This is an important point in distinguishing the mineral. The crystals of aegirine have a maximum size of 2.04 mm.  $\times$  0.085 mm., while aegirine-augite ranges 0.20 mm. to 0.38 mm. in length. Aegirine has a characteristic pleochroic scheme, viz.,  $X = \text{bluish green}$ ,  $Y = \text{light green}$  and  $Z = \text{yellowish brown or brownish yellow}$ .  $X > Y > Z$  and optically negative.

Biotite is abundant in this rock and occurs in minute flakes. It always has a remarkable brown color which is due to the titanium content and shows the following pleochroism, viz.,  $X = Y = \text{dark reddish brown}$  and  $Z = \text{light yellowish brown}$ .  $X = Y > Z$ ,  $N_m = 1.1657$ , and the  $2V$  is very small. This mineral is usually associated with magnetite. It alters to chlorite.

Magnetite is a very common mineral in all specimens and occurs in granular, euhedral, or skeletal forms. The euhedral and granular crystals are undoubtedly magnetite but skeletal ones may be titaniferous magnetite. The largest euhedral crystal is 0.6 mm. in diameter, but usually they are very small. The skeletal crystals do not exceed 1 mm. in maximum length. The ratio of both types varies greatly in different specimens. Sometimes the skeletal type is more predominant than the euhedral, while in other cases *vice versa*. The skeletal crystals often

have a very peculiar form and sometimes occur side by side surface of such minerals as augite or olivine. It is also notable that only the euhedral and granular varieties are included in olivine and augite.

Apatite has a long prismatic or acicular form and is abundant in many specimens. This mineral is always characterized by transverse cracks. The birefringence is very low. The crystal is not terminated by crystal faces but often shows a hexagonal cross section. The maximum dimensions are 1.02 mm. in length and 0.085 mm. in diameter.

Analcite generally fills the interstices of plagioclase laths. The primary origin of most of it is shown by the frequent close association with aegirine. There is no evidence that it was derived from nepheline, although it is sometimes of secondary origin. In some thin sections the analcite is abundantly present, but in others nearly absent. Rarely it is accompanied by chlorite, calcite, and zeolites. The latter has a low birefringence and negative biaxial character. Such zeolites always appear in minute irregular or radial aggregates characterized by a wavy extinction. Analcite often includes abundant apatite needles. In the specimens from Nyûnô-hô and a few other places plagioclase is replaced by analcite.

Beside the above mentioned minerals there are many secondary minerals, such as chlorite, serpentine, sericite, nontronite, etc. The chlorite, serpentine, and nontronite were chiefly derived from olivine. Sericite, on the other hand, is produced from plagioclase by hydrothermal action. Sometimes calcite replaces olivine.

The order of crystallization of the primary minerals is much complicated. In all cases the crystallization of plagioclases, magnetite, olivine, and apatite began earlier than other constituents. Since titaniferous augite often includes olivine and plagioclases its crystallization probably started later than those minerals. The euhedral crystals of magnetite are very frequently found in olivine, augite, and biotite, showing a long period of crystallization. Skeletal magnetite is undoubtedly of a later stage. Aegirine and aegirine-augite may be derived mostly from titaniferous augite during the later stages of crystallization. There is much

evidence that analcite or other primary zeolites were formed in the last stage of the solidification of magma when the hydrothermal activity was more pronounced. T. OGAWA has recently proposed for this the name "hystatocrystallization of zeolites".

(3) **Chemical Composition**:—The chemical composition of trachydolerite collected from this district was recently studied by KÔZU and SETO in the Tôhoku Imperial University. In an analysis (1) of a typical specimen from the north slope of Sanjô-san, the soda content is much higher than potash, while in one (2) collected by T. OGAWA from Gokokujôshi, near Kainei, they are in nearly equal amounts. The high content of soda is evidently due to the presence of analcite, aegirine-augite, and oligoclase. KÔZU classified the specimen from Sanjô-san as a trachydolerite with sodalite and analcite, but the chlorine content is not indicated in his chemical analysis. Hence the presence of sodalite is uncertain in this case. It is of interest that the percentage of silica, alumina, soda, and potash in the specimen from Gokokujôshi agrees closely with that in teschenite (4) from Rokkutsu (鹿窟) near Taihoku (臺北). The remarkable point is the high percentage of potash which suggests the occurrence of potash feldspar, but of course, it may be partly attributed to the abundance of biotite in this case.

	(1)	(2)	(3)	(4)	(5)
SiO <sub>2</sub>	50.26	47.08	47.82	47.56	48.74
Al <sub>2</sub> O <sub>3</sub>	19.23	13.41	17.98	13.21	15.84
Fe <sub>2</sub> O <sub>3</sub>	1.00	2.85	2.88	6.65	6.90
FeO	3.89	7.19	6.74	2.98	2.82
MgO	3.21	3.97	3.86	3.59	3.85
CaO	7.70	12.38	8.96	5.04	7.88
Na <sub>2</sub> O	7.69	4.83	2.66	4.20	2.65
K <sub>2</sub> O	4.39	4.91	5.88	4.64	3.54
H <sub>2</sub> O+	0.93	0.35	1.72	5.11	4.46
H <sub>2</sub> O—	0.29	1.81	0.67	.....	.....
TiO <sub>2</sub>	1.93	0.57	0.62	4.23	2.29

P <sub>2</sub> O <sub>5</sub>	.....	0.10	0.37	2.21	1.68
MnO	0.08	0.14	.....	.....	.....
Total	100.60	99.59	100.16	99.42	100.68

- (1) Trachydolerite, north slope of Sanjō-san. Analysed by K. SETO.  
 (2) " , Gokokujōshi, Analysed by K. SETO.  
 (3) " , Nanchūri, Shōkan-men, Shōjō-gun, N. Kankyō-dō. Analysed by K. SETO.  
 (4) Teschenite, Rokkutsu, Sekitei-shō near Taihoku, Taiwan (Formosa). Analysed by T. KŌNO.  
 (5) " , " , Analysed by T. KŌNO.

## ALKALINE GABBRO, OLIVINE TRACHYBASALT, AND BASANITE.

(1) **Distribution and Mode of Occurrence:**—Alkaline gabbro, olivine trachybasalt, and basanite are local differentiates from trachydolerite.

The alkaline gabbro is a coarse variety which does not show any doleritic structure under the microscope. It is irregularly distributed in trachydolerite, mostly in the interior of the laccoliths, sills, and dikes, and grades into trachydolerite. It is exposed in the intrusive masses of Nyūnō-hō, Sanjō-san, Endai-hō, Tōdō-toku, Sho-hō, etc.

The olivine trachybasalt and basanite are fine-grained and compact rocks with a black or dark grey color, which are common at Mafun-san, Seigi-hō, Katō-dō, etc. They mostly form marginal facies of trachydolerite and usually show a gradual transition to this rock. Trachybasalt and basanite usually occur in sills and laccoliths, but are found in the marginal facies of the prominent dike passing from Kando-hō to Endai-hō. They are also found in diamond drill cores of the marginal facies of trachydolerite sills. Trachybasalt, recently analysed by SETO, was collected by the writer from the north slope of Sanjō-san. The texture is usually a little finer than that common in trachydolerite. Rarely the basanite grades into glassy basalt at the contact. It makes up the marginal facies of the dike exposed on the north side of Endaigai.



(2) **Microscopical Characteristics** :—Typical alkaline gabbro (Pl. VIII, a, b) is a little coarser than trachydolerite. It is composed of oligoclase, andesine, labradorite, olivine, augite, biotite, aegirine, aegirine-augite, magnetite, apatite, and analcite. As is the case of trachydolerite, aegirine and aegirine-augite are sometimes absent. Orthoclase is, on the other hand, rarely found. The alkaline gabbro does not show porphyritic texture, and it is somewhat ophitic or doleritic in the intermediate stages of the gradation into trachydolerite.

Among the feldspars andesine or labradorite is more abundant than oligoclase. They have a stout prismatic or lath-shaped habit and are always characterized by both albite and carlsbad twinnings. Oligoclase can easily be distinguished from other plagioclase by its lower index of refraction, the usual absence of albite twinning and the nearly straight extinction. It is mostly found as an interstitial material to the crystal of andesine or labradorite.

Aegirine-augite- or aegirine-bearing varieties were collected from Nyûnô-hô and the north slope of Sanjô-san. These minerals occur as small independent crystals or as borders to the titaniferous augite. Their amount is not large.

Titaniferous-augite and olivine are very common minerals. Occasionally they are euhedral in form. Titaniferous augite generally has a fresh appearance, but the olivine often shows alteration to such minerals as serpentine and nontronite. Both minerals have inclusions of apatite. Biotite is also one of the important minerals but it is negligible in certain specimens from Nyûnô-hô :

Needles or long prismatic crystals of apatite and granular and euhedral magnetite are among the earliest crystallized minerals. They are abundant in all the thin sections. The magnetite is frequently associated with biotite.

The most noteworthy character of this rock is the abundant occurrence of analcite. It always fills the interstices of the other constituents and partly replaces plagioclase. Its frequent occurrence together with aegirine or aegirine-augite is strong evidence for its primary origin.

Olivine trachybasalt and basanite have a very characteristic texture under the microscope (Pl. IX, a, b and Pl. X, a). Megascopically it is sometimes porphyritic but generally aphanitic. The writer collected porphyritic varieties from the lowest part of the sill exposed at Katô-dô and at the ends, upper or lower, of the diamond drill cores obtained at Daitô-dô (大塔洞).

Textural changes from intersertal to fine pilotaxitic are frequent. Relatively coarser varieties (olivine trachybasalt) are found in the transition stage to trachydolerite. Olivine trachybasalt and basanite are usually composed of andesine, labradorite, olivine, augite, aegirine, aegirine-augite, biotite, magnetite, analcite, and apatite.

Andesine and labradorite are abundant in all specimens, but the phenocrysts are usually restricted to the very fine-grained rocks. They appear generally in lath-shaped crystals with a length from 0.05 mm. to 0.8 mm., and are usually twinned after the carlsbad or albite law.

The augite, in part titaniferous, commonly has a prismatic or granular form and is generally rare as phenocrysts even in the fine grained rock. It always has a very fresh appearance. Together with magnetite, analcite, olivine, biotite, etc. it fills the interstices of plagioclase. Augite is exceptionally abundant in the specimens from Suitên-dô (水站洞).

Olivine is also an important constituent, occurring as phenocrysts and in the groundmass. As phenocrysts it is often euhedral and is 2 mm. or more in maximum diameter. Inclusions of magnetite are frequent. It readily weathers to serpentine, chlorite, and calcite. The alteration of olivine into carbonates is often observed in the basanite from Shôtô-dô (小塔洞).

Apatite decreases in amount in the fine-grained variety, but magnetite increases. This is particularly seen in the marginal facies where magnetite is exceedingly abundant.

Biotite is always present, sometimes in association with magnetite. Aegirine and aegirine-augite are not so frequently seen as in trachydolerite. Aegirine-augite and aegirine-bearing trachybasalt were found at Endaigai.

Analcite is in association with the above mentioned minerals as interstitial material to the plagioclase. It is, of course, of a primary origin, as in trachydolerite and alkaline gabbro.

The mineral composition of these three different rocks quite resembles that of trachydolerite. It is very interesting that aegirine and aegirine-augite are frequently observed in alkaline gabbro, but are nearly absent in olivine trachybasalt and basanite. Oligoclase has a similar distribution. The abundance of oligoclase, aegirine and aegirine-augite in alkaline gabbro undoubtedly indicates an increase in the sodium content toward the interior of the igneous body. Analcite diminishes in the marginal facies. The cause of these phenomena will be explained in another section.

The alkaline gabbro in this district is somewhat similar to the coarse variety of analcite-bearing diabase, viz., teschenite, collected from Rokkutsu, near Taihoku, although the fresh olivine is entirely absent in the rock. The mineralogical composition, as well as its texture, suggest that this alkaline gabbro is an *esserite*.

(3) **Chemical Composition:**—The fine grained variety obtained on the summit of Sanjō-san was called trachybasalt by Kōzu.<sup>1)</sup> However, the specimen analysed contains abundant olivine which is also seen in all other specimens with a fine texture, and they are therefore partly basanite. The chemical analysis (1) gives a high content of magnesia, which is due to the presence of olivine.

The low percentage of soda and potash, compared to that of trachydolerite, is also quite characteristic, indicating a marked decrease of alkalis near the contact. The chemical investigation of the basanite and alkaline gabbro in this district has not been completed, but the very similar alkaline gabbro has been analysed by Sero. The specimen analysed was collected by K. Honda from Nanchū-ri of Shōkan-men, a short distance north of the Kainei district. It is characterized by a high content of alkalis particularly potash, and a low percentage of magnesia.

1) S. Kōzu and K. Sero:—The Chemical and Microscopical Studies of Some Korean Rocks. Abstract of Paper from the Fourth Pacific Science Congress in Java (1929).

	( 1 )	( 2 )
SiO <sub>2</sub>	49.27	50.75
Al <sub>2</sub> O <sub>3</sub>	20.30	18.07
Fe <sub>2</sub> O <sub>3</sub>	0.41	2.91
FeO	7.82	6.39
MgO	6.43	0.07
CaO	10.84	8.85
Na <sub>2</sub> O	1.78	3.00
K <sub>2</sub> O	0.51	6.33
H <sub>2</sub> O+	0.60	1.67
H <sub>2</sub> O—	0.13	0.54
TiO <sub>2</sub>	1.62	0.72
P <sub>2</sub> O <sub>5</sub>	0.14	0.91
MnO	0.33	0.04
Cl	tr.	tr.
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Total	100.18	100.25

(1) Olivine trachybasalt, Summit of Sanjō-san, analysed by K. SETO.

(2) Alkaline gabbro, Nanchūri, Shōkan-men, Shōjō-gun, N. Kankyō-dō, analysed by K. SETO.

## ALKALINE SYENITE.

(1) **Distribution and Mode of Occurrence** :—Alkaline syenite is not common and occurs only within laccoliths and dikes of trachydolerite. The modes of occurrence are as dikes and in masses (Pl. V.). The former is more common than the latter, and is well developed at Kando-hō, Chūtoku (仲徳), Endai-hō, Shōchōdōsoku-san, and Gensan-dō cutting trachydolerite in a network or a parallel arrangement (Pl. V, a). The masses, as frequently observed in the vicinity of Endai-hō, are ovoid in form (Pl. V, b) with maximum major and minor diameters of 250 m. and 150 m. respectively. The two types are generally associated, indicating some genetical connection. This may be clearly seen at Endai-hō where

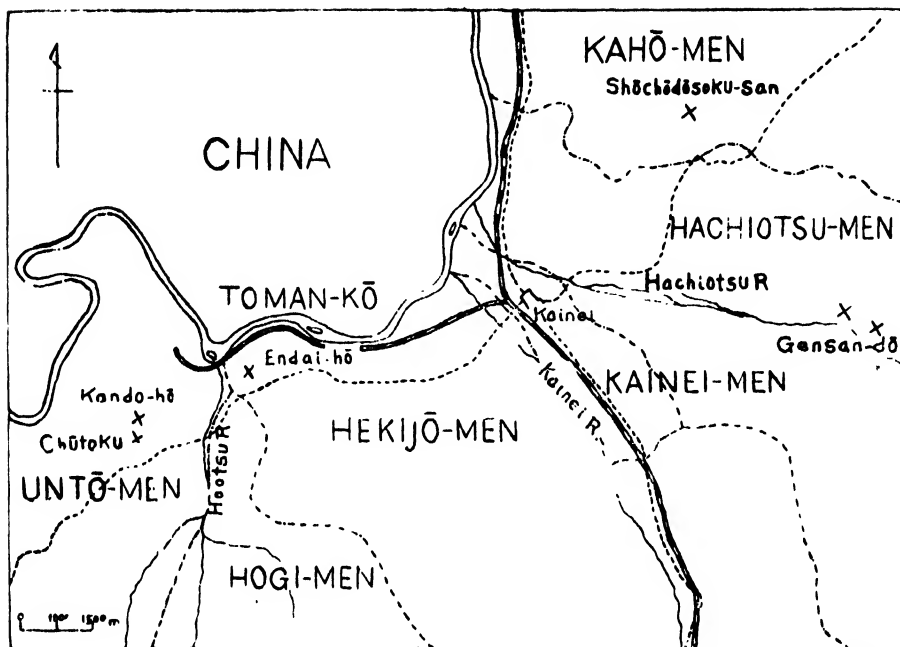


Fig. 1. Chart showing the main localities of alkaline syenite in the Kainei district.

many parallel dikes, mostly 2 to 10 centimeters in width, are exposed near a massive body. At Chōtoku (Fig 2) and Kando-hō occurs as a very complicated net-work in which some of the dikes branch into many minor dikelets whose widths usually vary between 1 and 5 centimeters. The writer found a similar occurrence at Gensan-dō. The dikes at Shōchōdōsoku-san have a maximum thickness of about 30 cm. The alkaline syenite from Chōtoku, Kando-hō, and Endai-hō are in the same dike of trachydolerite, which extends from the north-eastern side of Gokokujōshi to the Chinese territory. The ranges of texture, from fine to coarse, are only seen in the large masses, such as that of Endai-hō. Commonly there is an abrupt gradation into the inclosing rock—trachydolerite—which often shows an especially coarse texture near the transition zone. On account of the rather strong resistance to weathering this rock has a tendency to project conspicuously above the surface of the surrounding rock.

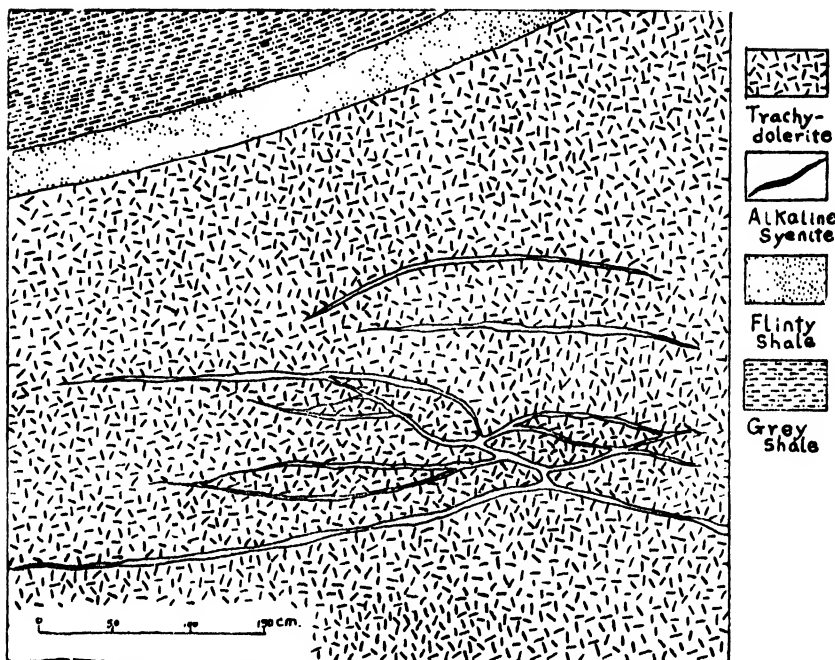


Fig. 2. Diagram showing the net-work of alkaline syenite in trachydolerite.

(2) **Microscopical Characteristics:**—The alkaline syenite is a hard light grey-colored rock with a rough fracture. Mirolitic cavities are frequent. The mineral composition of this rock is somewhat variable in the different localities. Typical specimens (Pl. X, b) were collected from Endai-hô where it is well exposed in both dikes and masses. The alkaline syenite found here is generally composed of orthoclase, augite, biotite, aegirine, aegirine-augite, barkevikite, analcite, apatite, and magnetite, while, along the contact, titaniferous augite is sometimes found. Some of the colored minerals are absent in other localities.

In all cases the most prominent mineral is orthoclase which commonly occurs in the anhedral or subhedral form. In the larger bodies the crystal habit varies, being equidimensional in the central part and lath-shaped in the marginal zone. The maximum diameter is 4 mm. Carlsbad twinning is particularly common in the lath-shaped crystals.  $n_z = 1.525$  on 010. It is partly zeolitized and kaolinized.

The augite is anhedral or subhedral, increasing in size toward the interior of the bodies. The largest crystal is 2 mm.  $\times$  1 mm. in size. It often shows an octagonal cross-section with distinct cleavage parallel to 110. Extinction angle:  $Z \wedge c = 38^\circ$ . It generally has inclusions of magnetite and sometimes biotite. Augite is very frequently surrounded by narrow zones of aegirine and aegirine-augite, similar to the augite in trachydolerite. In such cases they have quite different extinction angles, viz.,  $Z \wedge c = 56^\circ$  or more in aegirine-augite, and  $X \wedge c = 3^\circ$  or thereabouts in aegirine. The largest crystal of aegirine reaches 1.7 mm.  $\times$  0.68 mm. in size. Its pleochroism is very conspicuous:  $X$ =bluish green,  $Y$ =light green,  $Z$ =yellowish brown or brownish yellow;  $X > Y > Z$ . This pleochroism is nearly the same as that of the aegirine-augite. Optically, however, aegirine is negative while aegirine-augite is positive. The minerals are anhedral in form and always grade into each other. Aegirine is absent in the specimens from Chûtoku and Kôshin-dô (孔心洞).

Barkevikite is a common mineral in the alkaline syenite from Endai-hô and Kando-hô, being specially plentiful in the former place. It shows a tendency to increase toward the center of the masses. The crystals are mostly long, prismatic in form, and give a very characteristic pleochroism, viz.,  $X$ =light brownish yellow,  $Y$ =reddish brown,  $Z$ =deep brown;  $Z \wedge Y \wedge X$ . The pleochroism is very distinct in the basal section. Twinning parallel to 100 is common. The extinction angle is very small;  $Z \wedge c = 5^\circ$ . It is 1.7 mm. in maximum length and 0.14 mm. in maximum width.

Biotite is found abundantly in the specimens from Endai-hô, but it is noteworthy that this mineral is entirely absent in those collected from Kando-hô (Pl. XI, b). Its pleochroic color is different from the ordinary type, being  $X$ =light yellow,  $Y$ =yellowish brown,  $Z$ =reddish brown;  $Z \wedge Y \wedge X$ . The crystals are always tabular; the finer ones are usually seen along the margin of the intrusion. The index of refraction is  $N_m = 1.667$  and  $2V$  is very small. The maximum diameter is 2.4 mm. Magnetite is a common inclusion. Sometimes biotite is included in orthoclase in which it shows a narrow light colored border.

The granular and euhedral crystals of magnetite, 0.7 mm. in maximum diameter, are widely distributed in all thin sections. Some of these crystals have a narrow reaction rim of biotite and are partly altered to hematite or limonite.

Apatite has a long hexagonal prismatic or needle-shaped crystal form. It is 1.5 mm in its maximum length and occurs as inclusions in orthoclase or biotite.

Analcite occurs in all specimens, filling the interstices of the other constituents. It is both primary and secondary. This is proved by the presence of aegirine or aegirine-augite as inclusions in it, similar to the like occurrence in trachydolerite, alkaline gabbro, etc. Sometimes analcite replaces orthoclase. The alteration generally starts from the margin or from the cracks in the crystal.

Natrolite is associated with analcite, forming radial aggregates or tufts, particularly in geodes. It occurs as very beautiful needles, 3 cm. in maximum length, associated with the icositetrahedron of analcite, 3 mm. in maximum diameter. Most of the natrolite is considered to be a primary constituent, as it fills the interstices of the orthoclase in a manner similar to analcite.

It is evident from the above description that biotite, magnetite, and apatite were crystallized in the earliest stage of solidification, and were followed by orthoclase and the pyroxenes. The zeolites were the final products in the consolidation of the magma.

The alkaline syenite in this region sometimes shows a fluidal arrangement of lath-shaped orthoclase. This is seen in the small dikes and along the contact of the large masses. It is undoubtedly a rapidly cooled phase, as it grades into a coarse granular variety toward the interior of the larger masses, such as that of Endai-hô. The contact between the alkaline syenite and the trachydolerite is usually sharp. Under the microscope there is a sudden change of minerals and textures (Pl. XI, a).

(3) **Chemical Composition** :—The alkaline syenites collected from Endai-hô were chemically analysed by K. SETO. The variety with a



fine texture was named "sodalite micro-syenite" by KÔZU. As can be seen from the chemical analysis (1) the most remarkable point is the high percentage of soda and potash together with the presence of chlorine and the absence of  $P_2O_5$ . The chemical composition of this rock is somewhat similar to the nepheline sodalite syenite from Nanchû-ri of Shôjô-gun which is intruded into trachydolerite. Some of alkaline syenites collected by K. HONDA from the above locality resemble those of the Kainei district, both megascopically and microscopically. Since apatite is entirely absent in some specimens, it is plausible to regard that the unusual content of chlorite may be due to a minor quantity of sodalite.

	(1)	(2)	(3)
SiO <sub>2</sub>	58.43	59.74	56.45
Al <sub>2</sub> O <sub>3</sub>	21.73	20.59	20.08
Fe <sub>2</sub> O <sub>3</sub>	1.56	2.21	1.31
FeO	1.75	1.35	4.39
MgO	0.88	0.17	0.63
CaO	2.53	2.44	2.14
Na <sub>2</sub> O	6.03	7.88	5.61
K <sub>2</sub> O	5.24	4.09	7.13
H <sub>2</sub> O+	1.23	1.38	1.51
H <sub>2</sub> O—	0.34	0.02	0.26
TiO <sub>2</sub>	None	0.23	0.29
P <sub>2</sub> O <sub>5</sub>	None	None	0.13
Cl	0.49	0.58	0.43
MnO	.....	.....	0.09
Total	100.24	100.68	100.45

(1) Sodalite micro-syenite, Endai-hô near Kainei. Analysed by K. SÊRO.<sup>1)</sup>

(2) Nepheline sodalite syenite, Nanchû-ri, Chôkan-men, Shôjô-gun, N. Kankyô-dô. Analysed by K. SÊRO.<sup>1)</sup>

(3) Sodalite syenite, Square Butte, Highwood Mountains, Montana. Analysed by W. H. MELVILLE<sup>2)</sup>

1) See Abstract of Paper from the Fourth Pacific Science Congress in Java (1920).

2) F. W. CLARKE :—The Data of Geochemistry, Bull. 770, U. S. Geol. Surv., pp. 452-453.

## THE OCCURRENCE OF SUBALKALINE ROCKS.

In addition to the alkaline rocks, there are abundant subalkaline extrusives and intrusives in Koyô-men (古邑面) and on the hilly area including Sansai-hô (山祭峰) and Rishûman-san (離秀滿山). They are plagioliparite, hornblende-biotite-andesite, hornblende andesite, porphyritic basalt and olivine basalt. The andesite always occurs as plugs and stocks, e. g., at So-san (嶺山), Yagan (矢岩), Kussan (窟山), etc. Plagioliparite is a local phase of the andesite.

Olivine basalt forms domes of variable size, while porphyritic basalt forms dikes which have parallel or radial arrangement, often cutting the andesite. This systematic arrangement of basalt somewhat resembles that of Unmu-rei (雲霧嶺) further north. Most of the andesite dikes are older than the trachydolerite and porphyritic basalt. At Shaotsu-dô andesite is cut by trachydolerite. The exposures of porphyritic basalt at the south-western foot of Kussan, are often accompanied by trachydolerite, but the relative age is unknown. Olivine basalt occurs away from the others and there is no relation between them.

## THE TEXTURAL AND MINERALOGICAL VARIATIONS OF ANALCITE-BEARING ROCKS.

Almost all the intrusive bodies show variations of texture and in mineral and chemical compositions from the contact toward the interior. Such phenomena are particularly noticeable in the large masses. The chemical and mineralogical investigations of these changes are important for the study of the differentiation of the magma. It is, however, usually difficult to collect complete specimens of a whole section across a body.

The writer collected specimens from sills of analcite-bearing rocks which are respectively 16.37 m. (No. 1), 36.02 m. (No. 2) and 3.49 m. (No. 3) in thickness. They are all from diamond drill cores. The

last of these (No. 3) was obtained from the depth of 344.83 m. below surface. Petrological and chemical studies of these cores has been started and the results will be published at a later date.

Differences, particularly in texture, were seen even in the smallest bodies as a result of the studies of thin-sections from every 10 to 30 cm. of the core,

At the borders of the sill the rocks are exceedingly fine-grained basanite which gradually passes into a coarser variety. It is a porphyritic rock characterized by a fine pilotaxitic ground-mass which contains abundant minute flakes of biotite. The phenocrysts are lath-shaped andesine and labradorite, augite and olivine. Plagioclase is often altered to calcite and chlorite, but augite, partly titaniferous, is commonly not decomposed. The olivine is entirely altered to chlorite, serpentine, or calcite, with preservation of the original crystal form. The ground-mass is composed of confused aggregates of flaky biotite, granular augite, lath-shaped plagioclase, magnetite, and analcite. Magnetite is not so abundant in the border facies as in the interior of the mass. The chilled facies is little thicker at the base of the sill than at the roof. In the thickest sill (No. 2) the thickness of this zone is 4 cm., and it is approximately the same in No. 1, but is absent from No. 3. At Shokyo-ri in the Chinese territory on the north side of Endaigai, a large dike cuts the Tertiary shale and sandstone, branching into a sill between the beds. The specimens collected from the direct contact of this dike are somewhat different from those from the above mentioned chill facies in that they contain an abundance of brown colored glass (Pl. XII, a). This rock is a glassy basalt with a black or dark grey color, consisting of andesine or labradorite, olivine, titaniferous augite, magnetite, biotite, analcite, and secondary chlorite and serpentine together with glass. The phenocrystic olivine is mostly anhedral or subhedral in form, often having been subjected to the magmatic corrosion. The largest crystal is 1.4 mm.  $\times$  0.61 mm. in size. Chlorite and serpentine were derived from this mineral.

Abundant granular augite and euhedral, granular, or skeletal magnetite together with a small quantity of flaky biotite are always in the ground-mass in association with glass. They fill the interstices of plagioclase laths. This glassy basalt passes into trachydolerite with a basanitic intermediate stage.

The texture of the basanite, as can be well observed at the roof and bottom of No. 1, No. 2, and No. 3, gradually changes, showing an intermediate phase of olivine trachybasalt (Pl. XII, b) toward the interior. All except the abnormal variety along the direct contact contain abundant magnetite in the ground-mass together with fine titaniferous augite, olivine, biotite, plagioclase, and analcite.

Similar specimens were collected along the lower contact of the sill at Katô-dô, where the various transitions to analcite-bearing rocks are seen. As already mentioned elsewhere, basanite is, or olivine trachybasalt and basanite are proportional to the size of intrusives, thus it is more strikingly developed in No. 2 than in No. 1 and No. 3. The thickness of this peripheral phase measured in No. 2 core is 55 cm. at the roof, but it is nearly twice that at the bottom.

The occurrence of basanite is not always restricted to the peripheral part, as it is often found in the interior of trachydolerite, where it forms small patches or thin streaks (Pl. XIII, a), about 1 cm. in maximum thickness. This is clearly seen in the sills above mentioned. In this case it is characterized by an abundance of biotite flakes and generally shows an abrupt textural change to trachydolerite similar to that of schlieren to the mother rock.

Many thin sections made from these drill cores, however, show that the sills are largely made up of trachydolerite. Trachydolerite sometimes changes into a coarser variety resembling essexite which has an irregular distribution, although most of it is in the interior of the sill. Therefore no great regularity of textural change is present. In the thin sills there is an abrupt decrease of grain size, toward the contact, compared with the more gradual change in the thicker ones. This is conspicuous in the No. 3 sill which is 3.49 m. in thickness. Changes in the

component minerals or of their percentages are not so noticeable as that of the texture. However, the proportion of analcite, apatite, and acid plagioclase to the other minerals is greater in the trachydolerite.

The percentage of analcite particularly increases in the central part of the sill where it not only fills the interstices of the other minerals, but forms patches or streaks, usually very small in size. These patches and streaks contain some augite, acid plagioclase, aegirine, aegirine-augite, biotite, nontronite, prehnite(?), and magnetite (Pl. XIII, b). They are more acidic in character than the surrounding part and the basanitic zone, and they are quite different in their texture and component minerals. Biotite is usually very scarce in them.

Aegirine and aegirine-augite occur more frequently in the interior of the mass. In sill No. 2 these minerals appear at 2.80 m. below the upper contact and nearly disappear at 3.39 m. above the lower contact. They are present in the innermost part of even such a small sill as No. 3. An intimate relation between these minerals and analcite is present in all cases.

Nearly similar changes of texture and mineral composition are observed in specimens systematically collected between the contacts of the sills and laccoliths at Kyokusui-dô, Gokokujôshi, Shinki-dô (舜基洞), and others, but aegirine and aegirine-augite are sometimes absent.

The concentration of the alkaline constituents in the interior of the sills indicates that a certain amount of differentiation has occurred. There is little evidence of a gravitative differentiation. The symmetrical gradation from an alkaline center to the chill facies of the roof and floor, instead of a more basic zone above the chill facies at the floor, indicates that gravity did not bring about the differentiation.

DALY<sup>1)</sup> has already pointed out the absence of fractional crystallization in most basaltic sills. He says "According to BOWEN's argument, diorite or even quartzose phases might be regularly expected near the roofs and ultra-femic phases near the floors." Such phases were not

1) R. A. DALY;—Genesis of Alkaline Rocks. Jour. Geol., Vol. XXVI, (1918), p. 118,

found even in the large intrusive bodies of the Kainei-Shōjō district which are believed to have cooled quite slowly.

In the later stages of the consolidation, the magmas were soda-rich as is indicated by the minerals formed. According to FENNER<sup>1)</sup> the formation of alkaline rocks is believed to be a result of an enrichment of soda and alumina due to the post-magmatic gaseous emanation. GILLSON<sup>2)</sup> has much the same view and says "The passing of soda-and alumina-bearing emanations through a subalkaline magma, thus enriching it in these elements, may thus have been one process by which alkaline magma have come into being." It seems that the original magma of analcite-bearing rocks in the Kainei-Shōjō district was already soda-rich when injected into the Tertiary sediments and the cooling was slow enough to allow the concentration of soda in the central portion of the bodies.

The occurrence of minor patches and streaks of the basanitic facies and frequent aggregates of augite within trachydolerite suggest local rapidly-chilled phases, while the confused aggregates of soda pyroxenes, zeolites, and acidic plagioclase are the last stages of consolidation.

## **CONTACT METAMORPHISM CAUSED BY THE INTRUSION OF ALKALINE ROCKS.**

The intrusion of the alkaline and associated subalkaline rocks caused contact metamorphism of sediments. In this the baking of the grey shales to black is a common phenomenon. At dikes the alteration is seen on both sides. Even small dikes, three or four meters wide, have a black colored shale aureole for one or two meters in width. The predominantly black shale beds along the Hootsu River were probably caused largely by the large dike passing through Kando-hō and Endaigai, but were partly due to the influence of the thick sill at the eastern

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1) C. J. FENNER:—The Ketmai Magmatic Province. *Jour. Geol.*, Vol. XXXIV, (1926), pp. 700-703.

2) J. L. GILLSON:—On the Origin of the Alkaline Rocks. *Jour. Geol.*, Vol. XXXVI, (1928), p. 473.

side of this river. At Katô-dô the shale has a black color for about five meters beneath the sill. It is very noteworthy that the shale beds are sometimes more strongly influenced along the lower contact than at the roof, as can be seen at Shinki-dô and elsewhere. Another kind of metamorphism is shown by the occurrence of dense shale hornfels. This alteration is very common in the neighbourhood of Seigi-hô and Kyûshin-bô. It is a very compact and hard rock with a varying color from dark grey to dark green or bluish grey. The fracture is conchoidal. The gradation of this shale hornfels to black shale away from the contact indicates that the former is a product of a stronger metamorphism of similar material. Generally only an induration of sandstone and conglomerate is seen in the field, e. g., at Katô-dô, etc., where they often occur together with shale hornfels.

Under the microscope the shale hornfels is seen to be composed of a very fine aggregates of quartz, feldspar, chlorite, epidote, magnetite, rutile, and pyroxene. This fine aggregate contains a variable amount of slightly coarser clastic grains of quartz and feldspar, these grains being angular in form. There has probably been considerable silicification of the shale. The black shale is composed of aggregates of minute angular quartz, magnetite, calcite, biotite, plagioclase, carbonaceous matter, muscovite, and very fine opaque material. The opaque material occurs in roughly parallel streaks. The sandstone is frequently much silicified, particularly close to the contact, where also biotite, chlorite, and muscovite were formed.

The intrusion of trachydolerite caused the alteration of lignite to natural coke or anthracite, this change being accompanied by a conspicuous decrease of the volatile matter and the water content and an increase of fixed-carbon. Natural cokes were collected in the abandoned tunnels of the Hôgi Coal Mine and Kanpoku (咸北) Coal Mine, and also in the valley near Seigi-hô. The occurrence of anthracite is known at Kamidaisô-dô (上大宗洞), Shimodaisô-dô (下大宗洞) and other places. A very interesting occurrence of the alteration of lignite to coking coal is in the Yûsen (有専) Coal Mine. Here a large dike crosses the eastern

side of the mine. The direct contact between trachydolerite and coal seam is not exposed, but the lignite is entirely changed to coking coal in its vicinity. The formation of natural cokes and anthracites seems to be influenced by the sedimentary covering and the size of the intrusion. At the Yûsen Mine the coking coal is covered by relatively impervious shale, while the anthracite is covered by relatively pervious sandstone. The escape of the gases through the covering is probably a very important factor. Around the larger intrusion, particularly dikes, coking coal is more apt to be found.

### CONCLUSION.

The Tertiary area of the frontier region in N. Kankyô-dô is the most important locality in Korea for alkaline rocks. They were intruded after the deposition of the Tertiary sediments identified as Miocene and occur as laccoliths, sills and dikes at various horizons in these sediments.

Predominant among these rocks is trachydolerite, which grades into such differentiation products as olivine trachybasalt, basanite, and alkaline gabbro. The soda-rich minerals increase in percentage toward the interior of the mass. The textural changes are usually symmetrical with regard to the upper and lower contacts. Dikes and masses of alkaline syenite are with the trachydolerite. The mode of occurrence indicates a genetic connection. Primary analcite is common in both of them. It is noteworthy that this mineral is frequently found with aegirine and aegirine-augite. The alkaline magma here seem to have been separated locally into two phases, acidic and basic, either in the original reservoir or after intrusion, when there was sufficient time for differentiation. The occurrence of alkaline syenite is restricted to the larger laccoliths and dikes of trachydolerite which cooled more slowly. Hence, the alkaline syenite was differentiated from the same magma as trachydolerite; ascending through and filling contraction cracks of the laccoliths or the dikes.



As to the origin of the alkaline magma, various theories have been advanced. DALY<sup>1)</sup> attributed the origin of some alkaline magma to the reaction between basaltic magma and limestone. According to his theory the formation of feldspathoids is considered to be due to desilication of the magma in which silica is carried downward by the heavy lime-silicates. In addition, the upward movement of alkali due to the escaping carbonic acid and other resurgent gases is an important factor. SHAND<sup>2)</sup> also considered that the assimilation of the invaded calcareous or non-calcareous rocks was a cause of undersaturation of saturated magma. In his recent paper<sup>3)</sup> he discusses the origin of feldspathoidal rocks by reaction between magma and limestone. Various relations between alkaline rocks and limestone are similarly recognized by ALLAN,<sup>4)</sup> FOYE,<sup>5)</sup> GUINSBERG,<sup>6)</sup> QUENSEL,<sup>7)</sup> VOGT,<sup>8)</sup> BRÖGGER,<sup>9)</sup> etc. The local assimilation or desilication due to additions of lime from limestone and dolomite probably occurs in certain minor cases, as can be expected from the fluxing power of these rocks on silicate melts. The occurrence of cancrinite, or primary calcite, is sometimes believed to have originated from the introduction of carbon dioxide. DALY's theory, however, can not be applied to the alkaline rocks of Korea, where they are entirely independent of the distribution of limestone or other calcareous rocks. This seems also to be true for the alkaline rocks of Taiwan (Formosa). In Korea no alkaline rocks have been found, up to date, within the Cambro-Ordovician limestone area where the limestone beds are intruded by various kinds of subalkaline rocks.

- 1) R. A. DALY:—Origin of Alkaline Rocks, *Bull. Geol. Soc. Amer.*, Vol. XXI (1910), p. 87; *Igneous Rocks and Their Origin*, 1914, p. 410; *Genesis of Alkaline Rocks*, *Jour. Geol.*, Vol. XXVI (1918), p. 97.
- 2) S. J. SHAND:—*Geol. Mag.*, Vol. X (1913), p. 511.
- 3) S. J. SHAND:—Limestone and the Origin of Feldspathoidal Rocks. *Geol. Mag.*, Vol. LXVII (1930), pp. 415-426.
- 4) J. A. ALLAN:—Geology of the Ice River District, *British Columbia Memoir* 55, *Geol. Surv. Canada*, 1914, p. 211.
- 5) W. G. FOYE:—Nepheline Syenite of Ontario. *Amer. Jour. Sci.*, XL (1915), pp. 434-436.
- 6) A. GUINSBERG:—Pierre le Grand a Petrograde, *Annales de l'inst. Polytech.* XXV, 1916, p. 435.
- 7) P. D. QUENSEL:—*Bull. Geol. Inst. Upsala*, XXII (1914), p. 129.
- 8) T. VOGT:—*Videnskapselskabetes Skrifter*, 1 *Mat. Naturv. Klasse*, Christiania, 1915, No. 8.
- 9) W. C. BRÖGGER:—Die Eruptivgesteine des Kristianiagebietes IV. *Vidensk. Selsk. Skr.*, I. *Mat. Naturv.*, KI., 1920.

BOWEN,<sup>1)</sup> on the other hand, believes that differentiation is controlled by crystallization. "The sinking of crystals and the squeezing out residual liquid are considered the all important instruments of differentiation, and experimental evidence is adduced to show that under the action of these processes typical igneous series would be formed from basaltic magma if it crystallized (cooled) slowly enough." He suggests the following origin for the alkaline rocks: "If the crystals of the biotite granite stage, including quartz, sink out of this liquid then the concentration of  $\text{NaAlSiO}_4$  will finally reach a stage where nephelite will begin to precipitate. There may also result a concentration of  $\text{CO}_2$ , S,  $\text{SO}_3$ , Cl, etc., sufficient to cause their precipitation in compounds such as cancrinite, lazurite, and sodalite minerals which are peculiar to nephelite syenites and related rocks..... Differentiation during crystallization from these very fluid (alkaline) magmas will take place very freely, and the formation of both highly femic and highly alkalic types (rich in feldspathoids) may result. The more 'basic' types of alkaline rocks are not, however, in all cases basic differentiates from nephelite syenitic magma..... Favorable conditions seem to consist in the opportunity of sinking, not only of the plagioclase crystals and femic minerals, but also of quartz crystals in sufficient amount. This may result relatively 'basic' alkaline magmas from which such rocks as basanite might be formed, and nephelite syenite itself as a light differentiated".<sup>2)</sup>

In the Kainei-Shōjō district analcite-bearing rocks were locally intruded in connection with subalkaline rocks which are rather subordinate in amount. There is, however, no field evidencedence that alkaline magmas were separated from subalkaline magmas by differentiation due to the sinking of crystals. Of course, the sinking or rising of crystals in magma is sometimes plausible and may be the true cause of diversity in igneous rocks, but it does not explain why there was no gravitative

1) N. L. BOWEN:—The Later Stages of Evolution in Igneous Rocks. Jour. Geol., Vol. XXIII (1915), Supplement, p. 90.

2) N. L. BOWEN:—Op. cit., pp. 56-57.

differentiation during the slow cooling of the larger sills or laccoliths of basaltic rocks in this region. This process may have taken place in the original magma reservoir at depth. As already pointed out, alkaline syenite is sometimes associated with trachydolerite. This syenite was probably formed by the squeezing out process as contended by BOWEN<sup>1)</sup> but it is only a local phenomenon in the last stage of consolidation. It is uncertain, however, the basic alkaline magmas abundantly intruded in the frontier region of Korea were separated from the original magma in a similar manner. There must have been more complicated mechanism done during the long interval when the magma was under high pressure.

DALY<sup>2)</sup> believes that the separation of liquid phases, apart from possible development of immiscibility, is very important and it is to be expected:—(1) if the magma at the time of emplacement in a large chamber was heterogenous; (2) if for any reason gases are concentrated locally within the magmatic body; (3) if the assimilation of country rocks, or of their volatile constituents alone, took place.

Whether the magmas were originally homogeneous or not, their heterogeneities ought to be brought about easily by various physico-chemical processes due to the partial crystallization, accumulation, or migration of volatile materials, migration of magma, assimilation of country rocks, etc. SMYTH,<sup>3)</sup> FENNER,<sup>4)</sup> GILLSON,<sup>5)</sup> BOWEN,<sup>6)</sup> CROSS,<sup>7)</sup> FOYE,<sup>8)</sup> and others agree in the theory that the work of gases or mineralizers is a cause in producing alkaline rocks. Both SMYTH<sup>9)</sup> and HARKER<sup>10)</sup>

- 1) N. L. BOWEN:—Crystallization-Differentiation in Igneous Magmas. *Jour. Geol.*, Vol. XXVII (1919), pp. 407-411; *The Evolution of the Igneous Rocks*, 1928, p. 234.
- 2) R. A. DALY:—Genesis of Alkaline Rocks. *Jour. Geol.*, Vol. XXVI, (1918), p. 132.
- 3) C. H. SMYTH, Jr.:—The Chemical Composition of Alkaline Rocks and its Significance as to Their Origin. *Amer. Jour. Sci.*, Vol. XXXVI (1913), pp. 40, 46.
- 4) C. H. FENNER:—Op. cit., pp. 700-703.
- 5) J. L. GILLSON:—On the Origin of the Alkaline Rocks. *Jour. Geol.*, Vol. XXXVI (1928), pp. 471-472.
- 6) F. L. BOWEN:—Later Stages of Evolution in Igneous Rocks. *Jour. Geol.*, Vol. XXIII (1915), Supplement, p. 56.
- 7) W. CROSS:—Lavas of Hawaii and Their Relations. *U. S. Prof. Paper*, 88, (1915), p. 90.
- 8) W. G. FOYE:—Nepheline Syenite of Ontario, *Amer. Jour. Sci.*, XL (1915), p. 430.
- 9) C. H. SMYTH, Jr.:—Op. cit., p. 42.
- 10) A. HARKER:—The Natural History of Igneous Rocks, 1896, pp. 12-33.

consider that their concentration along with that the alkaline probably depends on crustal dislocation by radial movement in the earth. This seems to be little different from BOWEN's supposition<sup>1)</sup> on the origin of the alkaline rocks due to the action of outside forces.

Aside from the above mentioned theories it is believable that the interior readjustment of the earth's crust, whether there is a visible influence on the surface or not, must be perpetually carried on. Such crustal movements may be a cause of the migration of magmas on a large scale or, *vice versa*. The chemical equilibrium of the magma under certain conditions would be disturbed by its migration and this would stimulate various physico-chemical processes during that time, giving rise to heterogeneity of the magma. Thus it is not unreasonable to suppose that undersaturated liquid phases will be separated from the original magma. The separation of alkaline magmas may be a particular case of differentiation which can not exist everywhere differentiation takes place.

The predominance of the alkaline rocks in a restricted area of Korea, including minor islands in the Japan Sea, seems to indicate a local accumulation of these magmas in particular places from which they were successively intruded and extruded. Some of them appeared soon after the deposition of some of the older Tertiary sediments. Among these are the analcite-bearing rocks in the frontier region of N. Kankyô-dô and the Ryû-dô (龍洞) alkaline basalt<sup>2)</sup> in the Meisen-Kisshû (明川吉州) district. The restricted distribution of analcite-bearing rocks within the Tertiary area of the Kainei-Shôjô district might be the result of the migration of such magmas due to the gravitative adjustment of the eroded portion. The intrusion and extrusion of the alkaline basic rocks were followed by enormous faulting which determined the direction of the present coast of north-eastern Korea and the course of the Tôman-kô River. This faulting was followed by the large eruptions of acidic alkaline rocks in the Meisen-Kisshû district.<sup>3)</sup>

1) N. L. BOWEN :—Crystallization-Differentiation in Igneous Magmas. Jour. Geol., Vol. XXVII (1919), p. 429.

2) F. YAMANARI :—Kayôhō-Kisshû-Shiho and Rinmei Sheet, Geol. Atlas of Chosen, No. 3; I. TATEIWA :—Kyokudô-Meisen-Shichihôsan and Kotan-dô Sheet, Geol. Atlas of Chosen, No. 4.

3) ditto.



**PLATE II.**

## **Explanation of Plate II.**

Looking north from Sansai-hô

- ( 1 ) = Seigi-hô, ( 2 ) = Mafun-san, ( 3 ) = Nyûnô-hô, ( 4 ) = Sanjô-san,  
( 5 ) = Rhôhô-san, ( 6 ) = Dome of olivine basalt.

The hills in the foreground are made up of Tertiary shale, sandstone, and conglomerate.







# **PLATE III.**

### Explanation of Plate III.

- a. The sill and laccolith of analcite-bearing rock separated by the alternate beds of shale and sandstone (Kyokusui-dô). ( 1 ), ( 3 ), and ( 5 )= Alternate beds of shale and sandstone, ( 2 )=Laccolith and ( 4 )=Sill.
- b. Gokokujôshi looking up from Gekka-dô. ( 1 ) and ( 3 )=Alternate beds of shale and sandstone, ( 2 )=Sill of trachydolerite.



a

b





## PLATE IV.

## **Explanation of Plate IV.**

Gokokujôshi looking up from Tôman-kô.

( 1 ) = Sill of trachydolerite, ( 2 ) = Talus, ( 3 ) = Tertiary sediments, ( 4 ) = Granite.

- b. Contact between the sill of analcite-bearing rock and the Tertiary sediments at Katô-dô. Both columnar and tabular joint structures are well developed in this case. Along the lower contact trachydolerite passes into a basanitic phase whose photomicrograph is shown in Plate X, a.

( 1 ) = Analcite-bearing rock, ( 2 ) = Alternate beds of shale and sandstone.



a



b





## PLATE V.

### **Explanation of Plate V.**

- a. Parallel dikes of alkaline syenite cutting trachydolerite (Endai-hô).

As = Alkaline syenite. Td = Trachydolerite.

- b. Oval-shaped mass of alkaline syenite in trachydolerite on the pass of Endai-hô.

As = Alkaline syenite. Td = Trachydolerite.



a

b





# PLATE VI.

## Explanation of Plate VI.

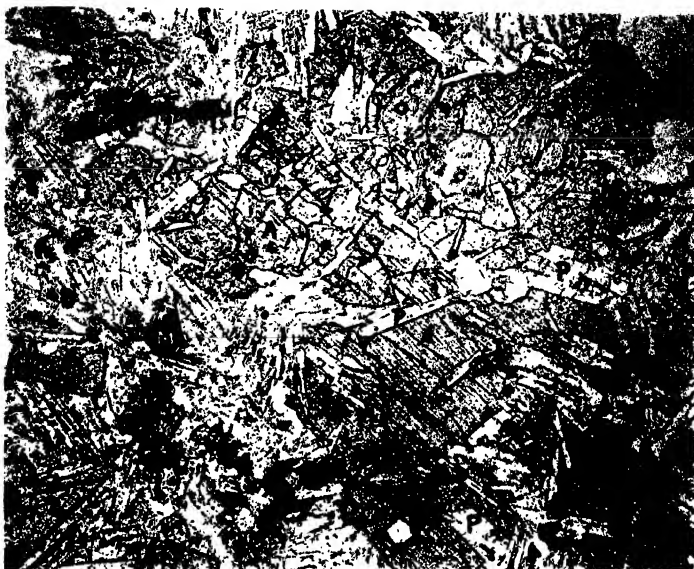
a. Trachydolerite (Gokokujōshi).

P = plagioclase, A = Titaniferous augite, O = Olivine, M = Magnetite, An = Analcite.

Titaniferous augite shows a poikilitic texture. × 60.

b. Trachydolerite (Katô-dô).

P = Plagioclase, A = Titaniferous augite, M = Magnetite, B = Biotite, An = Analcite, O = Olivine. × 60.



a

b







## PLATE VII.

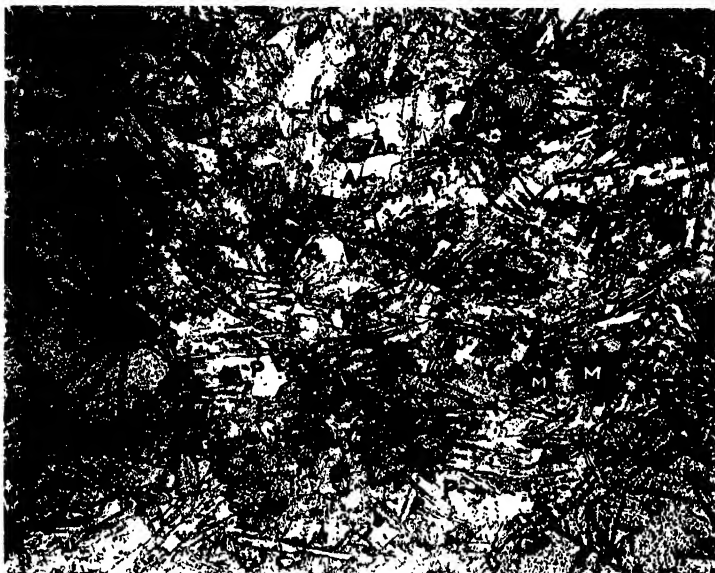
## Explanation of Plate VII.

a. Trachydolerite (Kyokusui-dô).

P = Plagioclase, A = Titaniferous augite, O = Olivine, An = Analcite, M = Magnetite.  $\times 60$ .

b. Trachydolerite (Diamond drill core) from Daitô-dô.

P = Plagioclase, A = Titaniferous augite, M = Magnetite, O = Olivine, B = Biotite, An = Analcite, Ap = Apatite.  $\times 60$ .



a

b





# PLATE VIII.

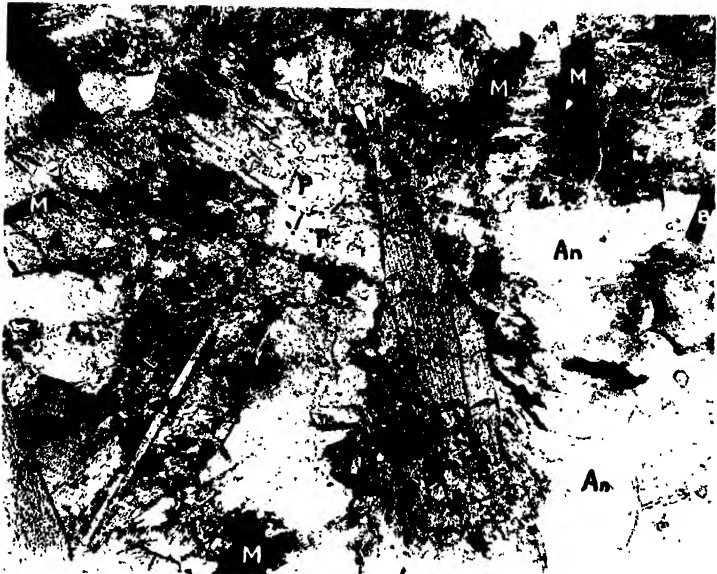
## Explanation of Plate VIII.

a. Alkaline gabbro (Suité-dô),

P = Plagioclase, A = Titaniferous augite, Ae = Aegirine, and aegirine augite, B = Biotite, An = Analcite, M = Magnetite, Ap = Apatite.  $\times 60$ -

b. Alkaline gabbro (Diamond drill core from Daitô-dô).

P = Plagioclase, A = Titaniferous augite, Ae = Aegirine and aegirine augite, B = Biotite, M = Magnetite, An = Analcite.  $\times 60$ .



a

b







## PLATE IX.

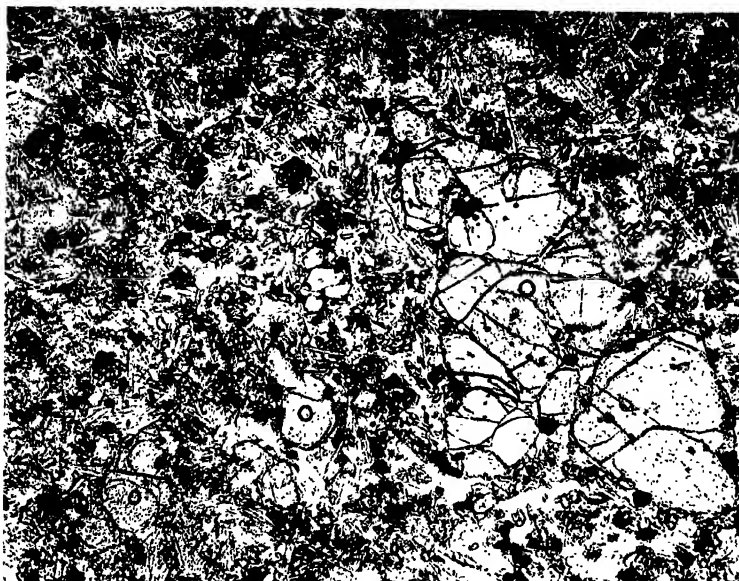
## **Expalanation of Plate IX.**

**a. Olivine trachybasalt (Mafun-san).**

O = Olivine. Black dots are magnetite and minute lath-shaped crystals are plagioclase. The ground-mass is made up of plagioclase, olivine, titaniferous augite, magnetite, biotite, and analcite.  $\times 60$ .

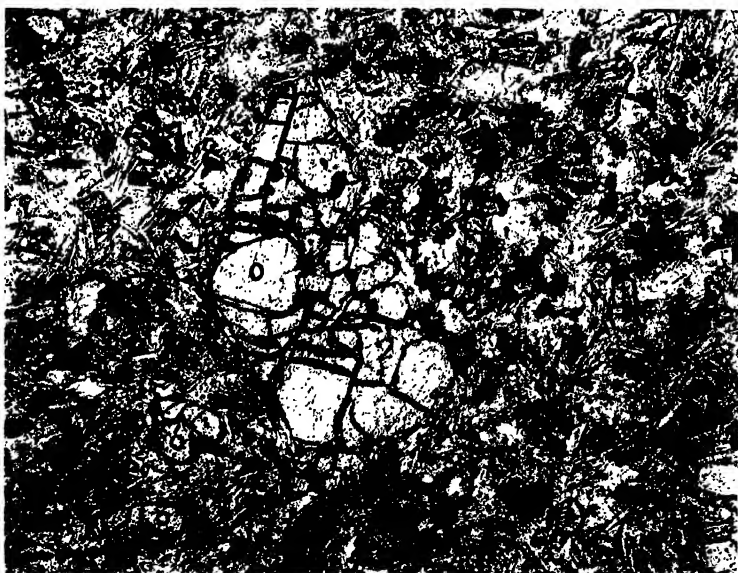
**b. Olivine trachybasalt (Kyûshin-dô).**

O = Olivine, An = Analcite. The ground-mass is made up of biotite, olivine, titaniferous augite, plagioclase, magnetite, and analcite.  $\times 60$ .



a

b





# PLATE X.

## Explanation of Plate X.

a. Basanite (Shôtô-dô).

P=Plagioclase, O=Olivine. The specimen was collected from the lower contact of sill. The ground-mass is composed of plagioclase, magnetite, biotite, and titaniferous augite. Olivine often changes into the secondary calcite.

× 60.

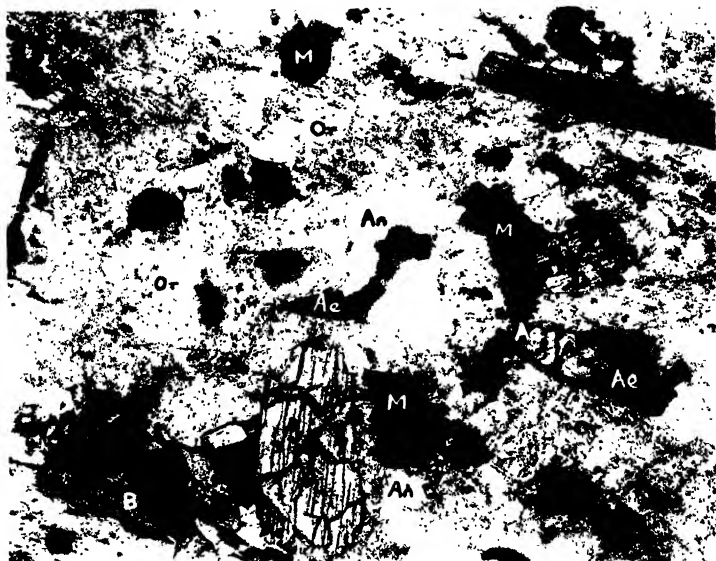
b. Alkaline syenite (Endai-hô).

Or=Orthoclase, A = Augite, M = Magnetite, Ac = Aegirine or aegirine augite, Ba = Barkevikite; B = Biotite, An = Analcite. Augite passes gradually into aegirine toward the margin of its crystal, always showing the intermediate stage of aegirine augite. × 60.



a

b







# **PLATE XI.**

## Explanation of Plate XI.

- a. The contact part between alkaline syenite and trachydolerite (Endai-hô).

The upper half is trachydolerite which is composed of plagioclase (P), olivine (O), magnetite (M), biotite, analcite, and apatite. The lower half is alkaline syenite. It consists of quite different minerals such as orthoclase (O), aegirine (Ae), aegirine-augite together with biotite (B), apatite (Ap), analcite (An), and magnetite. Alkaline syenite always shows a fine grained texture along the contact.  $\times 60$ .

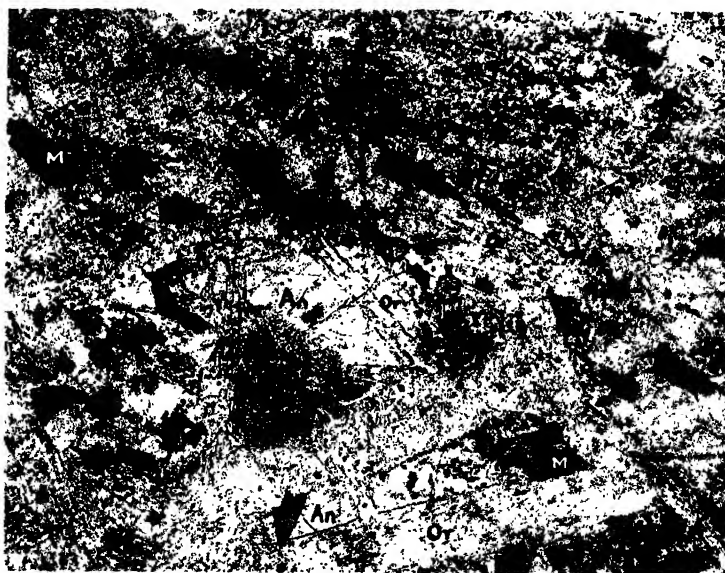
- b. Micro-alkaline syenite (Kando-hô).

Or=Orthoclase, A=Augite, Ae=Aegirine or aegirine augite, M=Magnetite, An=Analcite.  $\times 60$ .



a

b





## **PLATE XII.**

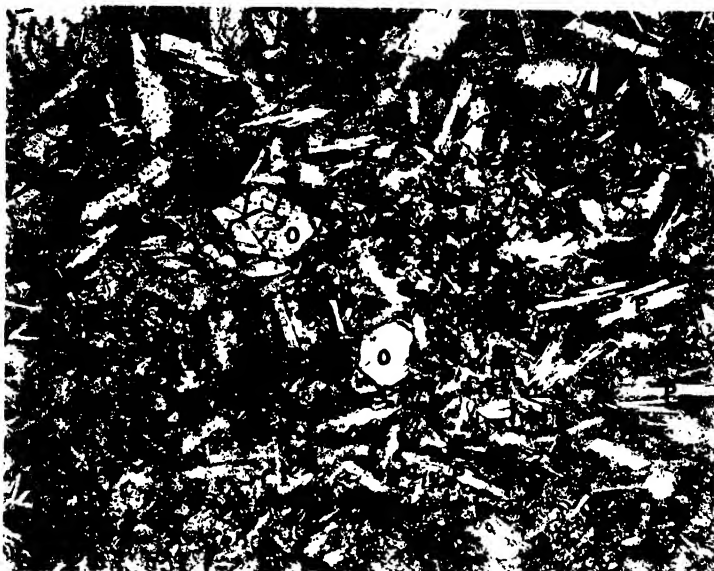
## Explanation of Plate XII.

a. Glassy basalt (Shokyo-ri).

P = Plagioclase, O = Olivine. The ground-mass is made up of plagioclase, olivine, magnetite, augite, and abundant brown-colored glass. Black dots and plates are magnetite. Granular crystals with the high relief are augite and olivine. The grey-colored filling stuff is glass.  $\times 60$ .

b. A transition between olivine trachybasalt and a basanitic phase (Diamond drill core from Daitô-dô).

P = Plagioclase, A = Titaniferous augite, O = Olivine. The ground-mass is built up of minute dots of magnetite (black), biotite flakes, augite grains, and plagioclase laths.  $\times 60$ .



a

b







## PLATE XIII.

### **Explanation of Plate XIII.**

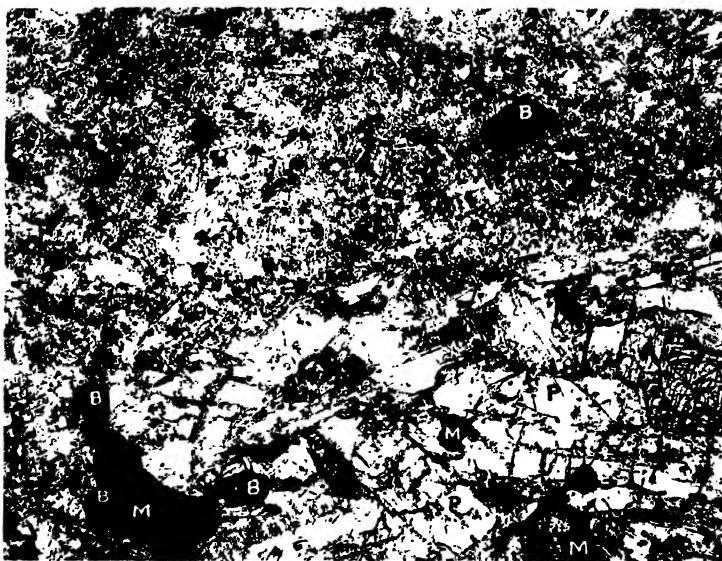
- a. A small patch of the basanitic phase. (Diamond drill core from Daitô-dô).  
P = Plagioclase, A = Augite. O = Olivine. The upper half is a basanitic phase which is composed of minute aggregates of magnetite (black), biotite (dark grey), augite (grains with high relief), olivine, analcite, and plagioclase.  
× 60

- b. A transition between trachydolerite and acidic phase (Diamond drill core from Daitô-dô). This acidic phase is found as a small irregular patch within trachydolerite.  
P = Plagioclase, A = Augite, B = Biotite, M = Magnetite, Ap = Apatite. Aegirine or aegirine augite is abundantly found in such an acidic phase, whereas biotite is usually very scarce. × 60.



1

b





# NOTES ON THE TITANIFEROUS MAGNETITE DEPOSITS OF SHÔ-ENPÉ-TÔ, CHÔSEN (KOREA).

By

Takeshi ICHIMURA.

With 4 Text-figures and 4 Plates.

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## INTRODUCTION.

Although the investigation of the titaniferous magnetite ores of Chôsen is interesting both geologically and economically, it has been rather neglected by our geologists. The only published works are some

papers which were written by S. KAWASAKI and M. HOSHINA<sup>1)</sup> many years ago and, recently, the results of heating experiments on the ores by M. KAMIYAMA.<sup>2)</sup> These experiments gave very interesting results, especially on the origin of "Widmannstätten's structure" which is very commonly observed in the titaniferous magnetite ores. According to the previous workers the mode of occurrence of the ores is variable. Some of them are associated with such characteristic rocks as anorthosite and amphibolite, to which their origin is referred.

As to the titaniferous magnetite deposits of Shō-enpé-tō (小延平島), however, only little was known up to the present, the only published report being a brief description done by E. TAMURA<sup>3)</sup> in 1913. It was reported by him that this island was mostly made up of older paleozoic rocks and the titaniferous magnetite deposits which are conformably overlain by a quartzite bed. The character and origin of the ore deposits were not discussed.

A few years ago the writer obtained some specimens of these ores and studied many polished section. The mineral associations showed that ores were undoubtedly of an magmatic origin. Last summer, accompanied by B. IRŌ, a teacher of the Higher Common School of Kaishō, I had an opportunity to visit this island and brought back many specimens of the rocks and ores, which I recently studied in the Geological Institute of Taihoku Imperial University.

The writer's field work was aided by the Police Department of Kōkai-dō, and the chemical analyses of the iron ores were kindly made by the Mitsubishi Iron and Steel Works of Kenjiho. Thanks are also due to Mr. S. G. CLARK of the University of California for much assistance in the writer's work.

- 
- 1) Mineral Resources of Chōsen (Korea), Vol. VI, No. 2, Vol. VII, No. 1. (In Japanese).
  - 2) M. KAMIYAMA:—The Report of a Heating Experiment of Titaniferous Magnetite from Korea, Jour. Geol. Soci, Tōkyō, Vol. XXXVI, 1928, pp. 12-29 (In Japanese).
  - 3) Mineral Resources of Chōsen (Korea), Vol. III, No. 1, pp. 65-66. (In Japanese).

## LOCATION OF AREA.

Shō-enpé-tō is a very small island (Figs. 1 and 2) which is 1.26 sq. km. in area and is located about 24 miles south of Ryūtōho (龍塘浦),

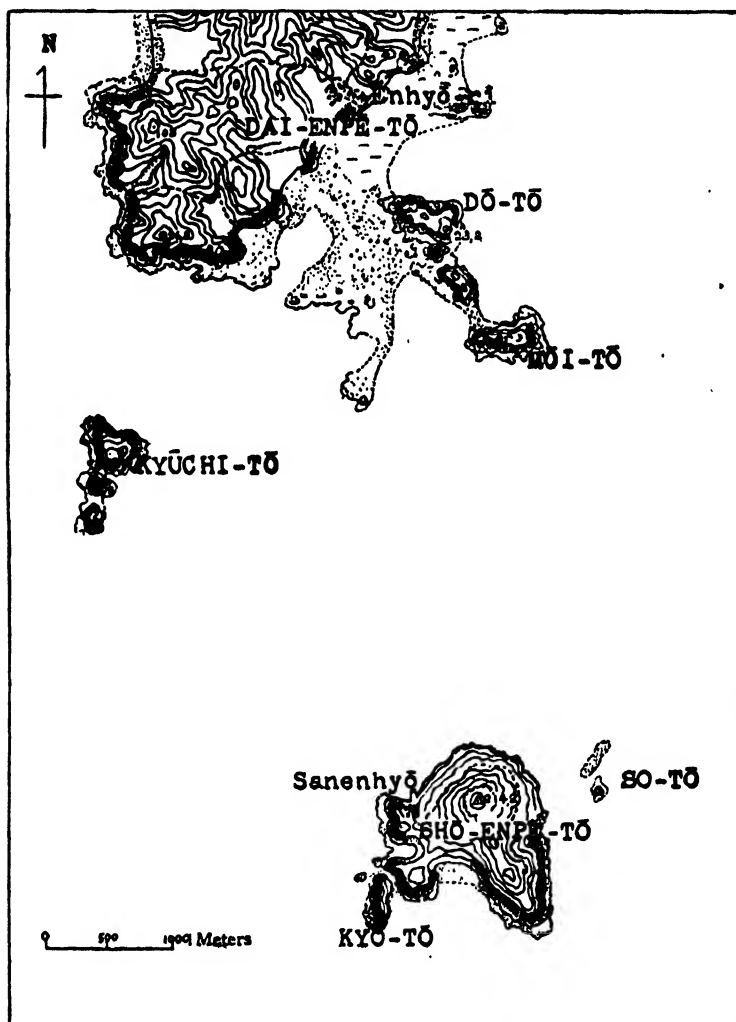


Fig. 1. Topographical map of Shō-enpé-tō, including a part of Dai-enpé-tō

a small harbour 4 km. south-east of Kaishū (海州). It is approximately enclosed by the parallels  $37^{\circ} 35'$  and  $37^{\circ} 37'$  N, and the meridians  $125^{\circ} 42'$  and  $125^{\circ} 45'$  E. It is surrounded by a shallow and rough sea,



and is extremely cliffed in many places. The highest point is found near the northern end, attaining 214.2 m. A small fishing village called San'enhyō (山延平), having a population of about two hundred, is located on its western side. This is the only village and harbour. Communication with the mainland is almost lacking except during the fishing season, which is spring.

### GEOLOGY.

The island is almost entirely made up of metamorphic rocks which are frequently intruded by dikes and covered by Quaternary sediments

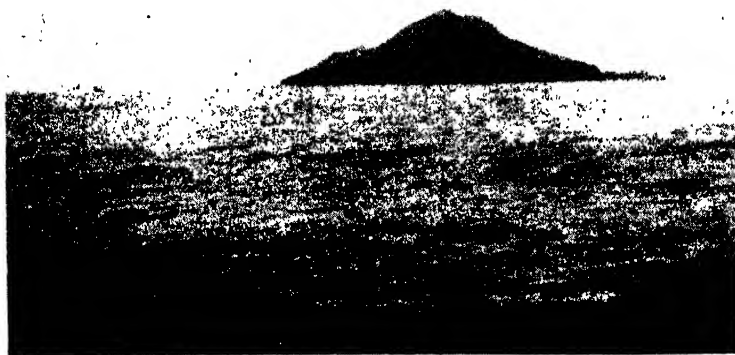


Fig. 2. Shō-enpé-tō looking from the north. the outcrops of titaniferous iron-ores near the summit are distinctly shown by the topographic difference. In the right side there is a small fishing village called San'enhyō.

(Figs. 3 and 4). Some of the metamorphic rocks are also found in the southern half of Dai-enpé-tō (大延平島), an island about one mile north (Fig. 3), and there they are intruded by biotite-hornblende granite. The granite observed there extends to the northern islands and its intrusion was, of course, an important factor in metamorphism of the rocks of Shō-enpé-tō.

(1) **The metamorphic rocks:**—They are biotite schist, biotite-hornblende schist, hornblende schist, muscovite schist, quartz schist and marble. The most predominant of them is a hornblende schist which

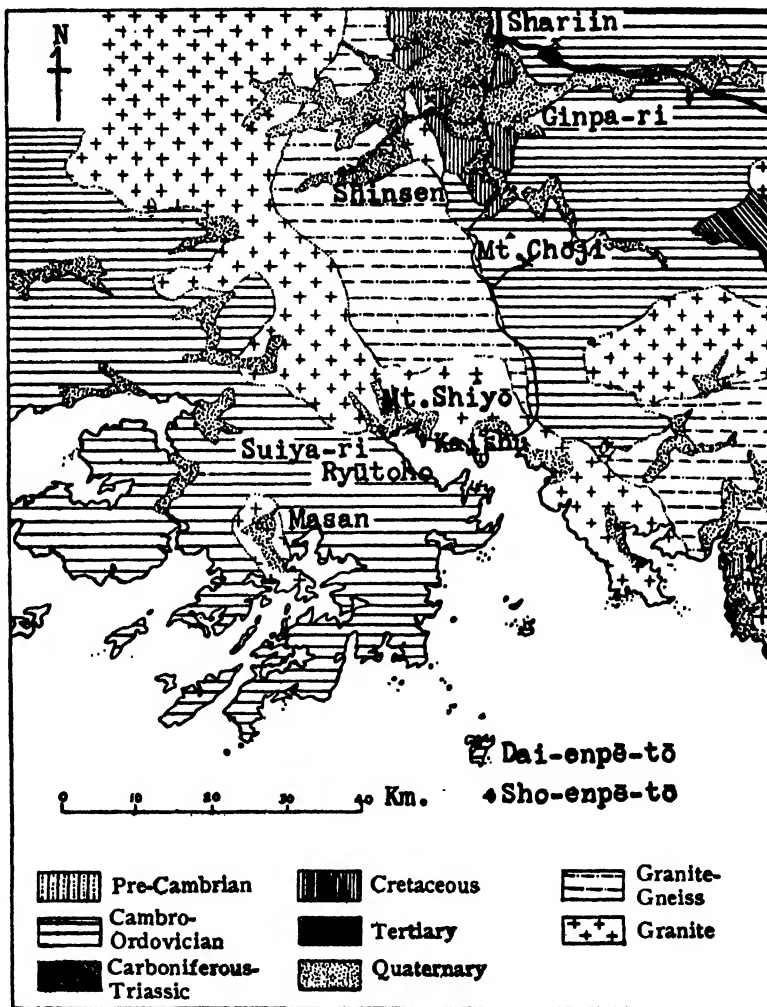


Fig. 3. Geological map of a part of Kōkai-dō, including Shō-enpé-tō.

contains many lenses of marble, both large or small, and is associated with the titaniferous magnetite deposits. It is exposed widely in the eastern half of the island, extending from north-west to south-east and generally dipping steeply to the north-east, but locally dipping SW

(Fig. 4). This rock has a dark green color and a banded structure usually due to the presence of abundant patches of plagioclase. It is composed of hornblende, andesine, rutile, magnetite, ilmenite, brookite, garnet, apatite, zircon, sericite, and limonite. Hornblende and plagioclase are always abundantly present.

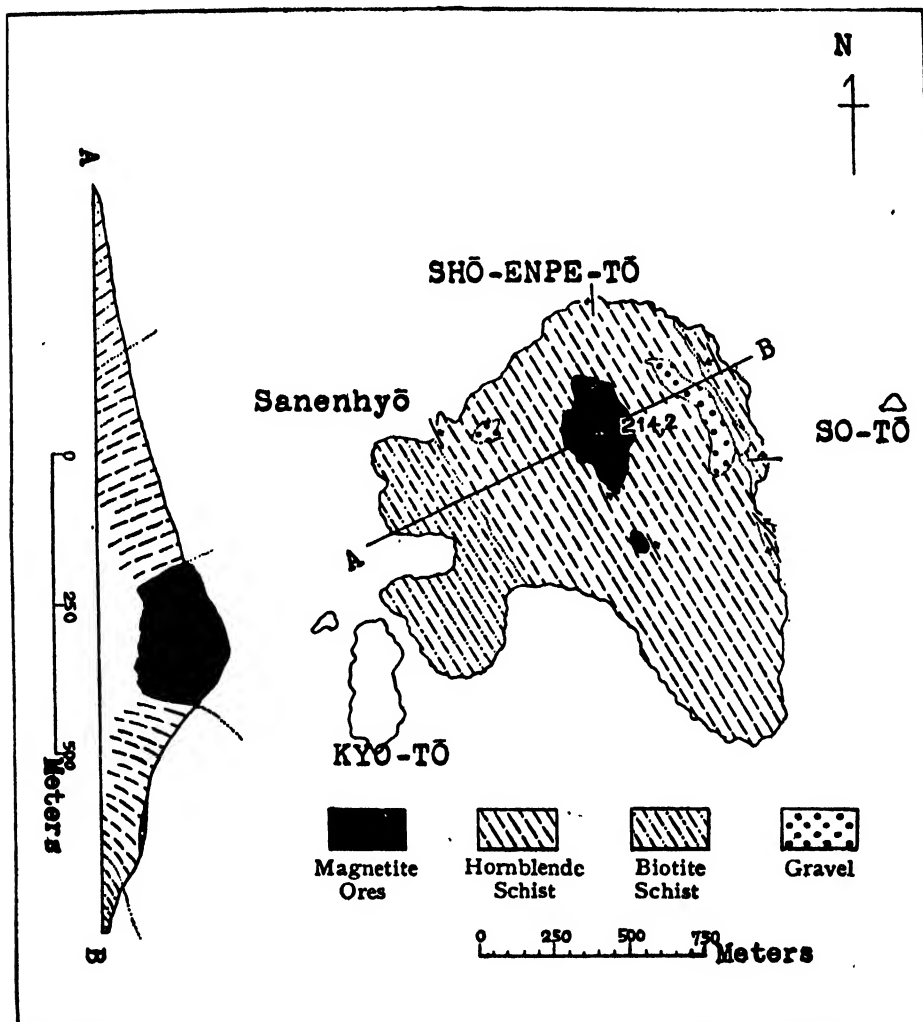


Fig. 4. Geological map of Shō-enpē-tō.

The distribution of biotite schist is restricted to the eastern and the western coasts. It is closely associated with hornblende schist and a

gradual transition between them is seen. Biotite-hornblende schist is well exposed along the N.W coast near San'enhyô as a transitional phase. The mineralogical composition of the biotite schist is commonly biotite, andesine, quartz, muscovite, zircon, pyrite, sillimanite, and tourmaline. Along the coast near San'enhyô garnet is an additional constituent. The garnets have a maximum diameter 5 mm. The biotite schist is at a lower stratigraphic horizon than the hornblende schist. The upper part of the series appears to have originally been calcareous, which is indicated by intercalated limestone lenses, hence the hornblende schist was probably formed from calcareous sediments.

The symmetrical exposure of the beds of biotite is due to a synclinal structure which can be observed along the northern coast. Both the muscovite schist and quartz schist are unimportant local intercalations in the biotite schist.

The marble lenses are more common along the eastern coast than in the other parts of the island. They have a grey color and usually consist of abundant diopside and quartz, a small quantity of biotite, green hornblende, rutile, chlorite, zoisite, and clinozoisite in association with calcite. Sometimes the limestone grades into confused aggregates of wollastonite, in which are many crystals of hedenbergite and diopside. Garnet and plagioclase are rarely observed.

Almost all of these rocks are beautifully stratified, showing a strike of N30°W and a dip of 10°-75° NE or SW, except where some local disturbances occur on the eastern side of the island.

The geological age of these rocks is uncertain at present, as they were not traced northward to determine their position in the Paleozoic section on the mainland. However, it is considered that the many small islands in Kaishû Bay were originally connected with the Paleozoic area of the mainland where the Chôsen system (Cambro-Ordovician) is widely distributed in association with huge intrusive masses of granite. One of the characteristic features is the occurrence of many metamorphic rocks due to the granitic intrusion, as can readily be seen along the boundaries of the Chôsen system near Ryûtôho and Suiya-ri (翠野里) of the Kaishû

district. Therefore, it is not unreasonable to say, as has been reported by E. TAMURA, that there are many points of similarity between these rocks and those of Shō-enpé-tō.

(2) **Quaternary sediments**:—The metamorphic rocks are partly covered by recent gravel beds which contain many shells of *Ostrea*. They are well exposed on the eastern slope of the highest peak and on the hill behind San'enhyō (Fig. 4). The pebbles are chiefly composed of metamorphic rocks and titaniferous magnetite ore. The beds are always found on a flat surface, which is an old marine terrace, and is usually fifty to seventy meters above sea level. This fact shows that there has undoubtedly been an upheaval in recent geological times. Similar evidence can be seen along the coast near Ryūtōho or elsewhere on the mainland.

(3) **Intrusives**:—Plutonic intrusions are not found on this island, but there are many small intrusives which were injected into the metamorphic rocks. They occur as sills and are composed of pegmatite, aplite, kersantite, and vogesite.

(a) **Pegmatite and aplite**:—The mode of occurrence of pegmatite and aplite is uncertain, since they were found only as angular blocks lying on the northern and the western slopes of the peak. They generally have a light grey color or are white, but are frequently stained by iron-oxide. The pegmatite is very coarse, while the aplite is fine grained. The mineral constituents of the pegmatite are orthoclase, andesine, albite, apatite, titanite, zoisite, clinozoisite, and sericite. In this case orthoclase and albite are the most prominent minerals, while quartz is absent. Orthoclase commonly contains many small patches of andesine, giving a perthitic intergrowth. Albite, as well as sericite, clinozoisite, and zoisite are secondary minerals derived from orthoclase and andesine. The mineral composition of the aplite found here is, on the other hand, only different from that of the pegmatite in that green hornblende and abundant quartz are present and orthoclase is absent.

(b) **Kersantite and vogesite** :— Small sills of lamprophyres, intruded between beds of biotite schist or hornblende schist, were observed in many places. A characteristic kersantite sill is exposed at two places along the beach near San'enhyō, where it occurs between biotite schist beds. At one of the places it is 0.32 m. while at the other it is 3 m. The sills of vogesite are very common between the hornblende schist beds exposed along the cliff of the eastern coast. They are usually from 2 to 4 m. in width.

The kersantite is a compact dark green rock composed of hornblende, labradorite, rutile, magnetite, biotite, apatite, pyrite, and sericite. The essential constituents are hornblende and labradorite. The hornblende is prismatic and occurs in more or less confused aggregates, including ilmenite, apatite, and rutile. It has a green color and is 0.85 mm.  $\times$  0.034 mm. in maximum size. The labradorite is lath-shaped with twinning after the albite or carlsbad law. When it shows a zonal structure, the inner part is generally more basic than the border. In association with it are many apatite crystals, which are long prismatic or needle-shaped. Rutile and magnetite are common accessory components, but biotite and sericite are negligible.

The vogesite is macroscopically similar in appearance to the kersantite. Its primary components are hornblende, andesine or labradorite, apatite, and magnetite. The hornblende, however, is somewhat different in appearance from that of the kersantite, having a slender prismatic habit, with the following dimensions, 1.2 mm. in maximum length and 0.25 mm.  $\times$  0.17 mm. in maximum size of the basal section. Its extinction angle is small, viz.,  $Z \wedge c = 18^\circ$  and twinning parallel to 100 is very common. The prisms are always turbid near the ends and show a characteristic pleochroism, viz., X=light yellow, Y=dark greenish brown, Z=dark greenish brown, and  $Z=Y > X$ .

A remarkable feature of this rock is that it subjected to a severe albitization. The quartz, calcite, and chlorite, which are associated with the secondary albite, are undoubtedly due to alteration during the albitization.

## TITANIFEROUS MAGNETITE DEPOSITS.

As already mentioned, the titaniferous magnetite deposits are associated with the hornblende schist. There are two bodies in the ridge which forms the backbone of the island, one of them being exposed at the upper half of the peak behind San'enhyō, while the other occurs at the south side of the pass. Because of its resistance to weathering, the first of these bodies gives a pronounced topographic effect (Fig. 2). At the western contact this ore-body has a strike of N 30° W and dips very steeply to the north-east. However, farther to the south, the angle of inclination gradually decreases and it finally thins due to erosion. It ends abruptly at the old sea cliff on the northern slope of the hill, where the top of the ore is at an elevation of 214.2 m. The body has an extent of about 300 m. along its strike and is about 200 m. wide, while it is only 50 or 60 m. in vertical extent.

The second ore body is much smaller. It dips 40° to the northeast and is underlain by hornblende schist.

Since they always occupy the upper part of the ridge, many blocks, large and small, have been broken off and are now widely scattered on the slope. This is particularly noticeable on the south-western slope. Some pebbles of these ores are also found on the beach and in the old gravel beds deposited on the marine terrace. In places where the ore bodies overlie the hornblende schist a sharp contact between the two is seen. The symmetrical arrangement of the schist indicating a synclinal structure, suggests that the ore bodies are remnants along the synclinal axis, and that the overlying beds were eroded away.

## ORES.

Many specimens were collected from various parts of outcrops. These ores were carefully studied by making thin sections and polished sections: some of them were chemically analysed at the Mitsubishi Iron and Steel Works.

They are very heavy ores with a black or steel grey color, usually somewhat mottled by the presence of green or red colored gangues which are irregularly arranged and fill up the interstices of grains of magnetite. There is a variation of grain, from fine to coarse; the coarser variety being commonly present in the higher grade ore.

(1) **Mineral composition of the ores:**—The ore is composed of magnetite, ilmenite, spinel, chlorite, and secondary minerals such as diaspora, goethite, limonite, and hematite. The relationship between magnetite and ilmenite was studied in polished sections etched with hydrochloric acid. In this etching the coarsely crystalline ore is more quickly acted upon by the acid than the fine-grained aggregates.

The etched magnetite shows a dull black color, whereas ilmenite remains bright. Magnetite grains are sometimes 1 cm. or more in diameter, while the ilmenite is found in them forming dots-like grains and in a reticulate structure ("Widmannstätten's structure"). These two forms are generally associated and there is frequently some connection between them. When ilmenite appears in dots, it has a polygonal form (Pl. II, a), with a maximum diameter of 3 mm. Generally it is irregularly scattered, but it is sometimes connected like a chain; occurring in three directions along the cleavage of magnetite. The chains sometimes coalesce to give a platy form with maximum dimensions of 0.034 mm.—0.05 mm. in thickness and 2.4 mm. in maximum length. Particularly interesting is the very frequent occurrence of minute reticulate structure separated by dots or large plates (Pl. II, b; III, a), although this pattern is not distinct in some specimens. Sometimes it is so plain that it can be seen even by the unaided eye. Minute plates always form a broken line, each plate of which is from 0.085 mm. to 0.3 mm. in length. Sometimes the plates occur in only one or two directions (Pl. III, b) but generally in a beautiful lattice intersecting at an angle of sixty degrees (Pl. IV, a). Very rarely four (Pl. IV, b) or five directions are seen, as described by SINGEWALD<sup>1)</sup> in the Adirondack ores. BRODE-

1) J. T. SINGEWALD, JR.:—Titaniferous Iron Ores in the United States, U. S. Bur. of Mines Bull., 64, 1913.



RICK<sup>1)</sup> however, has shown that there should be only four directions of lamellae as maximum. OSBORNE'S conclusion<sup>2)</sup> is that some of these lamellae are likely to be spinel which may easily be confused with the ilmenite, or it is possible that an mixing of ilmenite may take place parallel to the cube, as well as to the octahedron. WARREN<sup>3)</sup> noted that many of dots and rods called ilmenite by SINGEWALD are really spinel. In the specimens of Shō-enpé-tō, however, the irregular outline of the spinel always distinguishes it from ilmenite.

As to the origin of the reticulate patterns there are many different theories. After the investigation of titaniferous magnetite from Brazil, HUSSAK<sup>4)</sup> concluded that the intergrowth is due to the solidification of an eutectic. WARREN<sup>5)</sup> and SIGEWALD<sup>6)</sup> expressed practically the same idea. OSBORNE, on the other hand, has considered that magnetite was likely completely crystallized before ilmenite, since if it were eutectic it should have been entirely liquid until the last stage. According to RAMDOHR<sup>7)</sup> there is a considerable mutual solubility of magnetite and ilmenite at the temperature of separation of the ores, and there is an unmixing of ilmenite from the magnetite on cooling. He found that he could make the magnetite with intergrown ilmenite homogenous by heating. Hence he believes that unmixing took place at a temperature of from 700° to 800° C. KAMIYAMA<sup>8)</sup> recently studied by heating experiments the origin of this structure in many ores from Korea. As a result of this work

- 
- 1) T. M. BRODERICK:—Titaniferous Iron Ores of Minnesota, *Eco. Geol.*, Vol. 12, 1917, p. 686.
  - 2) F. F. OSBORNE:—Certain Magnetic Titaniferous Iron Ores and Their Origin, *Eco. Geol.*, Vol. 23, 1928, pp. 907-908.
  - 3) C. H. WARREN:—The Microstructure of Certain Titanic Iron Ores, *Eco. Geol.*, Vol. 13, 1918, p. 430.
  - 4) E. HUSSAK:—Ueber die Mikrostruktur einiger brasilianischer Titanmagnetitsteine, *Neues Jahrb. f. Min.*, 1904, I, S. 94.
  - 5) *Op. cit.* p. 440.
  - 6) *Op. cit.* p. 34.
  - 7) P. RAMDOHR:—Beobachtungen an Magnetit, Ilmenit, Eisenglanz und Ueberlagerungen über das System  $\text{FeO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ . Festschrift zur 150-Jahrfeier der Bergakademie Claustal, 1925, S. 371.
  - 8) M. KAMIYAMA:—The Report of a Heating Experiment of Titaniferous Magnetite from Korea. *Jour. Geol. Soc., Tokyo*, Vol. XXXVI, 1928, pp. 28-29 (In Japanese).

he suggested that the origin of the reticulate structure was due to the slow cooling which led to an exsolution of ilmenite. He believes that both minerals are in a solid solution and its eutectic temperature is about 1150°C, when the proportion is  $\frac{\text{magnetite}}{\text{ilmenite}} > \frac{75}{25}$ . The result of his laboratory work is somewhat different from that of RAMDOHR, especially on the temperature of the unmixing of both minerals. There is some probability that this temperature may be much influenced by pressure or other factors under natural conditions.

The characteristics of spinel (hercynite) can be more fully studied in the thin section than on a polished surface. It has a green color, is isotropic under crossed nicols, and often shows a cleavage parallel to 111. Generally it is disseminated in the titaniferous magnetite and is often enclosed by chlorite or diaspore. Sometimes subhedral or anhedral crystals of magnetite occur as inclusions. When it is subjected to the weathering it gradually changes into diaspore, limonite, goethite, and hematite along cleavage or other cracks. The largest crystal is 0.6 mm. in diameter.

Chlorite is a characteristic of this ore and always occurs in scaly aggregates of minute flakes. It shows a green color which often changes into reddish brown or yellowish brown upon decomposition. The size of the flakes range from 0.085 to 1 mm. in diameter. Its pleochroism is usually very weak, viz.,  $X=Y$ =pale green,  $Z$ =pale yellow or colorless,  $X=Y > Z$ . Strain shadows and polysynthetic twinning on 001 are very commonly observed. The index of refraction is  $N_m=1.5875$  and mineral character is positive. The optic angle is very small. It is probably clinocllore.

Diaspore is a secondary mineral which, together with limonite and goethite, was derived from hercynite. It is a colorless flaky mineral with high birefringence and positive biaxial character. In addition, perfect cleavage parallel to 010 and the straight extinction are characteristic. Goethite and limonite are abundant in the much weathered ores. They were both decomposition products of hercynite and chlorite.

According to the above microscopic observations it seems that magnetite and ilmenite were crystallized at almost the same time in company with spinel. Ilmenite and spinel seems to have generally separated from the magnetite, partly along its cleavages and partly as dots in it, under a certain condition favorable to their gradual consolidation and immiscibility. Furthermore, there can be seen a tendency of some of the spinel to have been crystallized parallel to the face of cube as pointed out by RAMDOHR. In all cases chlorite was formed during the last stage of crystallization.

(2) **Chemical composition of ores**:—Since the investigation of the titaniferous magnetite was neglected for so long, only little concerning the chemical composition is known at present. In the chemical analyses published by E. TAMURA many years ago the content of  $\text{TiO}_2$  was so low that it did not appear in the general composition.

The writer has collected many specimens from the various outcrops and some of them were recently analysed by the Mitsubish Iron and Steel Works, with following results:

	1	2	3	4	5	6	7	8
Fe	51.20	53.00	49.80	50.20	52.60	50.40	53.60	52.00
$\text{SiO}_2$	1.54	0.32	1.44	2.60	0.84	1.60	0.46	0.96
$\text{TiO}_2$	19.72	20.96	20.18	20.88	19.92	21.04	20.52	20.80
S	0.029	0.005	0.025	0.022	0.025	0.016	0.010	0.012
P	0.052	0.018	0.022	0.026	0.016	0.032	0.026	0.026
	9	10	11	12	13	14	15	
Fe	53.00	52.80	52.80	51.60	52.80	52.40	52.40	
$\text{SiO}_2$	1.14	1.04	0.84	1.48	1.48	1.94	1.40	
$\text{TiO}_2$	20.46	20.06	20.88	20.52	21.64	20.14	22.14	
S	0.024	0.008	0.008	0.005	0.005	0.011	0.005	
P	0.020	0.022	0.022	0.028	0.028	0.034	0.020	

1-2, Ores collected from the western slope near summit.

3-4 " " " the summit.

5-6 " " " the southern slope.

7-15 " " " the northern slope.

As can be seen in these results, the content of  $\text{TiO}_2$  ranges from 19.72% to 22.80% and the average is 20.66%. The content of Fe is from 49.80% to 53.60% its average being 52.04%.

## ORIGIN OF TITANIFEROUS MAGNETITE.

Since the various deposits of titaniferous magnetite of Korea have not been sufficiently investigated up to the present, it is very difficult to summarize or to discuss in detail their mode of occurrence or origin. As showed by KAMIYAMA<sup>1)</sup>, some of them are irregular masses enclosed by gneissic rocks, while others are sills injected in schists. At Komasan (高麗山) and Konan-san (古南山) it is said that anorthosite is associated with them. The deposits of Kansan-ri (乾川里)<sup>2)</sup> are believed to be veins cutting gneiss. The veins have a hornblende and fluorspar gangue.

The titaniferous magnetite of Shō-enpō-tō is found in the area of hornblende schist. In this point it has some similarity to those of Polun-tō (蘆音島) and Konan-san studied by KAWASAKI<sup>3)</sup> and KAMIYAMA<sup>4)</sup> although the occurrence of anorthosite and other basic rock is entirely unknown in Shō-enpō-tō, where the ore bodies are a sill and are sharply separated from hornblende schists.

The separation of iron ores from the original magma has already been discussed by many geologists. VOGT<sup>5)</sup> concludes that the ore minerals crystallized out as an aggregate in the still fluid magma, locally forming a modification. The same idea is gained from HARKER's suggestion.<sup>6)</sup> LINDGREN<sup>7)</sup> suggested that the ilmenite probably crystallizes first and settles to the bottom. RASTALL,<sup>8)</sup> however, believes that the metallic ores derived from basic magmas tend to separate first and to sink to the bottom, whereas those from acid magmas tend to separate last and

1) Op. cit., p. 13. (In Japanese).

2) Mineral Resources of Chōsen (Korea), Vol. VII, No. 1, p. 54. (In Japanese).

3) Mineral Resources of Chōsen (Korea), Vol. VI, No. 2, p. 72. (In Japanese).

4) Op. cit., pp. 13-14. (In Japanese).

5) J. H. L. VOGT:—Bildung von Erzlagertstätten durch Differentiationsprozesse in basische Eruptivmagma, Zeit. f. Prakt. Geol., 1, S. 4-11, 125-143, 257-284, 1893.

6) A. HARKER:—Carrock Fell. A Study in Variation of Igneous Rock Masses. Quart. Jour., Geol. Soc., p. 311-325, 1894.

7) W. LINDGREN:—Mineral Deposits, 1st Ed., 1913, p. 740.

8) R. H. RASTALL:—Physico-Chemical Geology, p. 199, 1927.

rise to the top. It is, of course, plausible, as concluded by KEMP<sup>1)</sup> that the separation of iron ores from the original magma takes place while they are both liquid, on account of an immiscibility due to cooling. The deposits of Shō-enpé-tō were probably formed by the injection of iron ore magma separated because of immiscibility and they are not due to differentiation *in situ*. This genesis is similar to that given by KAMIYAMA<sup>2)</sup> for the titaniferous magnetite of Konan-san and Polun-tō. Practically the same theory is supported by LINDGREN<sup>3)</sup> and OSBORNE<sup>4)</sup> for other deposits.

The fact that reticulate structure is very common in the ores collected from this island indicates the slow cooling of the injected ore magma. The numerous dikes near the deposits suggest that both were differentiates of the same magma. These dikes are probably the differentiation products from the granitic mass exposed in Dai-enpé-tō. The injection of the magma appears to have occurred after the enormous folding which was followed by great igneous intrusions.

In 1927 the writer published evidences that there were two periods of diastrophism in Korea and that large intrusions and extrusions of various igneous rocks accompanied these disturbances<sup>5)</sup>. The formation of many deposits of metallic and non-metallic minerals was undoubtedly associated with these igneous activities. It is still uncertain when the injection of titaniferous magnetite occurred, but the determination of the geological age of granite making up Mt. Shuyō-san, (首陽山) near Kaishō, will solve this important problem. If it is of the same age as the younger granites intruding the Daidō (大同) formation (Cretaceous), the period of formation of titaniferous magnetite here may correspond to

- 
- 1) J. E. KEMP:—Titaniferous Iron Ore of the Adirondacks. U. S. Geol. Surv., 19th Ann. Rept., 1897-1898, Pt. III, p. 384.
  - 2) Op. cit., p. 18-19, 25-26, 28-29.
  - 3) W. LINDGREN:—Mineral Deposits, 2nd Ed., 1919, p. 786, 3rd Ed., 1928, p. 863.
  - 4) F. F. OSBORNE:—Certain Magmatic Titaniferous Iron Ores and Their Origin, Eco. Geol., Vol. 23, 1928, p. 921.
  - 5) T. ICHIMURA:—The Deposits of Iron Ores in Korea. Jour. Chōsen Min. Assoc. Vol. 10, 1928, p. 44. (In Japanese). The writer now believes that those disturbances took place soon after the deposition of the Heian system (Carboniferous-Triassic) and in the later Jurassic.

that of the deposition of hematite, siderite, pyrite, barite, fluorite, zincblende, and so on, found in the extensive area of the Chōsen system and the Daidō formation of Kōkai-dō (黃海道).

## SUMMARY.

(1) Shō-enpé-tō is chiefly made up of a metamorphic series probably derived from Cambro-Ordovician sediments. In addition are the sediments of the old marine terrace and dike-rocks such as pegmatites, aplites, and lamprophyres.

(2) The deposits of titaniferous magnetite are found in the area of hornblende schist which was originally an impure limestone. Some dike-rocks are exposed around the deposits; lamprophyres being the most predominant and important.

(3) The deposits are always found in a concordant relation to the hornblende schist. Thus its mode of occurrence quite resembles that of Polun-tō and Konan-san. In this case the ore magma was probably injected along the beds of metamorphics.

(4) The iron ores here are composed of magnetite, ilmenite, hercynite, and chlorite in association with secondary minerals such as diasporite, limonite, goethite, etc. The very frequent occurrence of a reticulate structure in magnetite seems to prove that the ore magma was partly consolidated by slow cooling, as has been shown by KAMIYAMA's experiment. The writer concludes that the ilmenite crystallized at nearly the same time as the magnetite.

(5) Hornblende schist and other metamorphic rocks are the products of metamorphism brought about by the extensive intrusion of the granite exposed in Dai-enpé-tō and in the islands farther north. These metamorphic rocks had already been subjected to much diastrophism before the injection of the ore magma, which followed the intrusion of granite.

(6) From the investigation of many deposits at other places in Kōkai-dō, it is probable that the metallization of the deposits here was probably connected with the large igneous activity of the later Cretaceous.

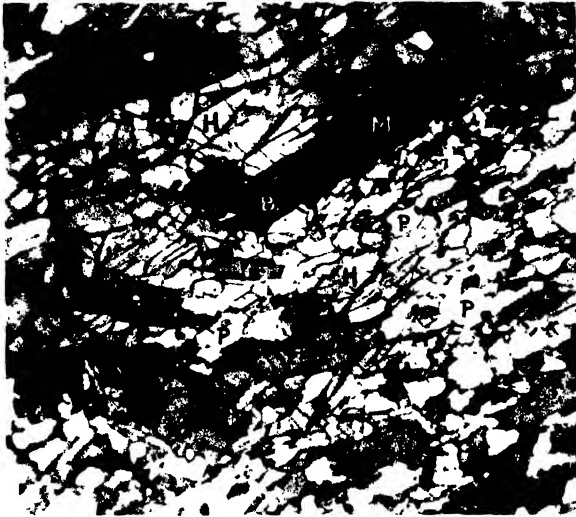
## **Explanation of Plate I.**

### **a. Hornblende schist.**

**H = Hornblende, P = Plagioclase, M = Magnetite, B = Brookite.    × 60**

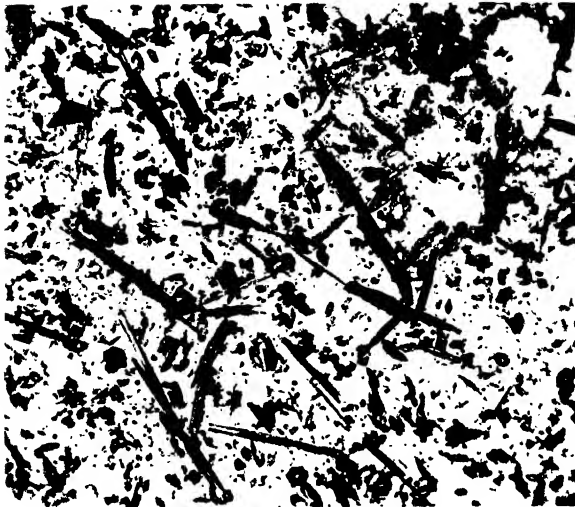
### **b. Vogesite from the eastern part of the island.**

**The dark grey-colored mineral is hornblende and other parts are composed of  
labradorite, rutile, magnetite, biotite, apatite, pyrite, and sericite.    × 60**



a

b







## **PLATE II.**

## **Explanation of Plate II.**

- a. Ilmenite which has a polygonal or platy form.  $\times 150$
  
  
  
  
  
  
  
  
  
  
- b. A reticulate pattern of ilmenite separated by dots of the same mineral connected like chains.  $\times 150$



a

b





## **PLATE III.**

### **Explanation of Plate III.**

- a. Ilmenite showing a reticulate structure and irregular dots.

I = Ilmenite, M = Magnetite, S = Spinel.    × 150

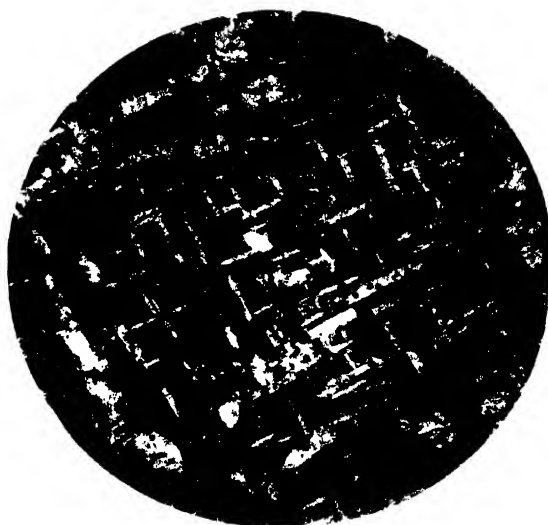
- b. A Lattice of ilmenite (the lines intersecting at right angles).

I = Ilmenite, M = Magnetite, S = Spinel.    × 150



a

b







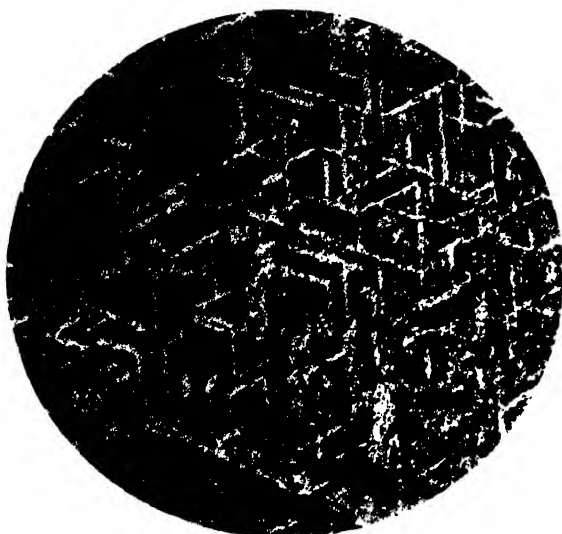
## PLATE IV.

### **Explanation of Plate IV.**

- a. A beautiful lattice of ilmenite (the lines intersecting at  $60^\circ$ ).

I = Ilmenite, M = Magnetite, S = Spinel.  $\times 150$

- b. A lattice of ilmenite with the lines in four directions.  $\times 150$



a

b





# ADULARIA FROM THE KARENKO REGION, TAIWAN.

By

Takeji KÔNO.

With 1 Text-Figure and 1 Plate

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## INTRODUCTORY.

Scientific papers concerning the mineral adularia are many. We can trace them back as early as the year 1830, when BREITHAUPt described it under the name of *valencianite* because it had been found in the Valencia mines in Mexico. Among the early records of the occurrence of this mineral those of the United States and New Zealand should be mentioned. Although the occurrence of this mineral is now known in various parts of the world, and although the mineral has been studied mineralogically and physico-chemically by many scientists, such investigations were not done in our country before Prof. S. Kôzu published, in 1929, his laborious work on the same mineral occurring in the Takatama mines, Hukusima Prefecture in North Japan.<sup>1)</sup> Takatama is not

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1) S. Kôzu, S. FUKAMI and K. KINOSHITA, The Journal of the Japanese Association of Mineralogists, Petrologists and Economic Geologists, 1929, vol. 2, p. 51. K. SÊTO, the same Journal, 1929, vol. 1. p. 278.

the only locality for the occurrence of adularia, there being several other places where it is known to have been found.

In this note I intend to report the occurrence of adularia in the island of Taiwan. During the summer of 1929, Mr. H. SAITÔ, professor of geology in the Government High School of Taiwan, Taihoku, collected a number of rock specimens in the eastern part of the island which is famous for its very precipitous cliffs hanging along the shore. In some of them well crystallized feldspathic minerals are found on the surface. The crystals being incrustal and impregnated by chlorite, the real mineralogical nature could not be decided. On examining some of the good specimens optically, physically, and chemically, the writer has been able to determine the mineral to be adularia.

In the next summer (1930), I had the opportunity of visiting the locality of this mineral, by the kindness of Prof. I. HAYASAKA, who took the trouble of accompanying me, and secured a number of specimens, some of which are much better, as well as larger, examples, well crystallized and free from chlorite dirt.

## OCCURRENCE.

The place where the crystals of this mineral were collected is near the small hamlet of Gôkutu, about 25 km north of Karenkô. Here the road along the side of the high and steep cliff passes along cuttings as well as through tunnels, in a metamorphic series of rocks. In the south of Gôkutu the rock formation is predominantly a grayish white chlorite schist (partly gneissic in appearance). A number of quartz veins run across the wall of the cliff as seen along the road: they are 10–30 cm in width, and are mostly open ones, with on both walls, druses of small prismatic crystals appearing greenish in colour. The crystals under consideration are mostly of quartz and adularia, both being spoiled superficially and internally with minute platy chlorite grains. The crystals of quartz and adularia are roughly estimated to be in the ratio

of about 40:60. It is rather difficult in the druses to obtain white, translucent crystals of purer adularia, although several good specimens were found which had fallen from the wall at the foot of the cliff.

The mineral is characterized by the rhombohedral form of its crystals, which are about 0.7–1.5 cm in length and 0.3–1.0 cm in width.

### FORM OF THE CRYSTALS.

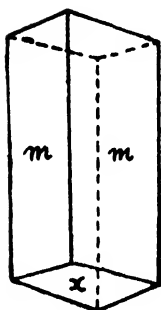


Fig. 1  
A Crystal of  
Adularia.

The crystal form is rather simple:  $m(110)$  and  $x(101)$ .

$c(001)$  is scarcely developed, but it is represented by the plane of perfect basal cleavage in some of the crystals.

$$x \wedge m' = 69^\circ 15'$$

$$m \wedge m'' = 61^\circ 08'$$

These angles have been measured with Fuess reflection goniometer, taking the mean value of twenty each. It is worthy of note that the face  $m(110)$  is almost always twisted a variable degree.

### PHYSICAL AND CHEMICAL CHARACTERS.

Under the microscope it is observed that even the crystals that are apparently single are divided into several portions that are extinguished at different positions.

The occurrence of the chlorite enclosure also is well shown under the microscope (Pl. I, Fig. 3).

Indices of refraction estimated by the immersion method are as follows:

$$\alpha' = 1.518$$

$$\gamma' = 1.524$$

$$\gamma' - \alpha' = 0.006$$

The oils used for these determinations were carefully preserved in brown bottles in a dark box, and influences of temperature, etc. were corrected each time with an Abbe refractometer.



The chlorite in the adularia is distinctly crystallized in hexagonal prisms, but most of them are elongated and curved along the vertical crystallographic axis, consequently always cleaving along the basal cleavage.

Pleochroism strong: X = green, Z = light yellow.

Chemical analyses have been carried out by the writer of both relatively pure and chlorite-impregnated specimens. The results are as follows:

	No. 1 (relatively pure part)	No. 2 (chlorite-impregnated part)
SiO <sub>2</sub>	65.25	57.87
Al <sub>2</sub> O <sub>3</sub>	17.63	18.97
Fe <sub>2</sub> O <sub>3</sub>	0.07	2.94
FeO	0.03	2.13
MgO	0.13	2.34
CaO	0.13	0.60
Mn <sub>2</sub>	0.86	0.82
K <sub>2</sub> O	15.69	11.78
H <sub>2</sub> O—	0.33	0.64
H <sub>2</sub> O+	0.52	2.63
Total	100.62	100.72

From analysis No. 1 the percentage of orthoclase molecule (Or), albite molecule (Ab), and anorthite molecule (An) are calculated as follows:

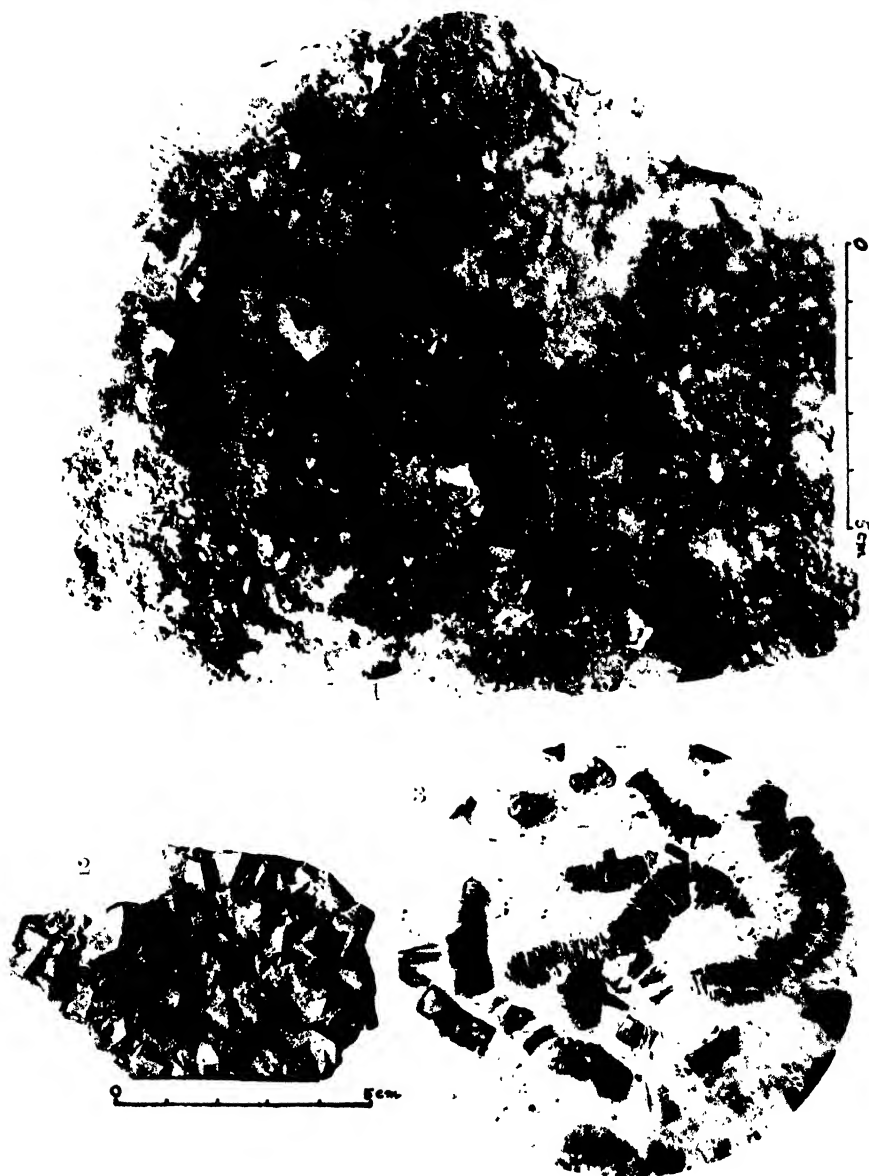
Or	91.14
Ab	7.60
An	1.26

In conclusion, I wish to offer my hearty thanks to Prof. HAYASAKA for his much appreciated advice and help in this work.

# **PLATE I.**

### **Explanation of Plate I.**

- Fig. 1.** Aggregates of adularia on its country-rock (chlorite-schist).
- Fig. 2.** An aggregate of adularia.
- Fig. 3.** Adularia (showing the chlorite in it): section perpendicular to the vertical crystallographic axis. Parallel nicol.  $\times 69$ .





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